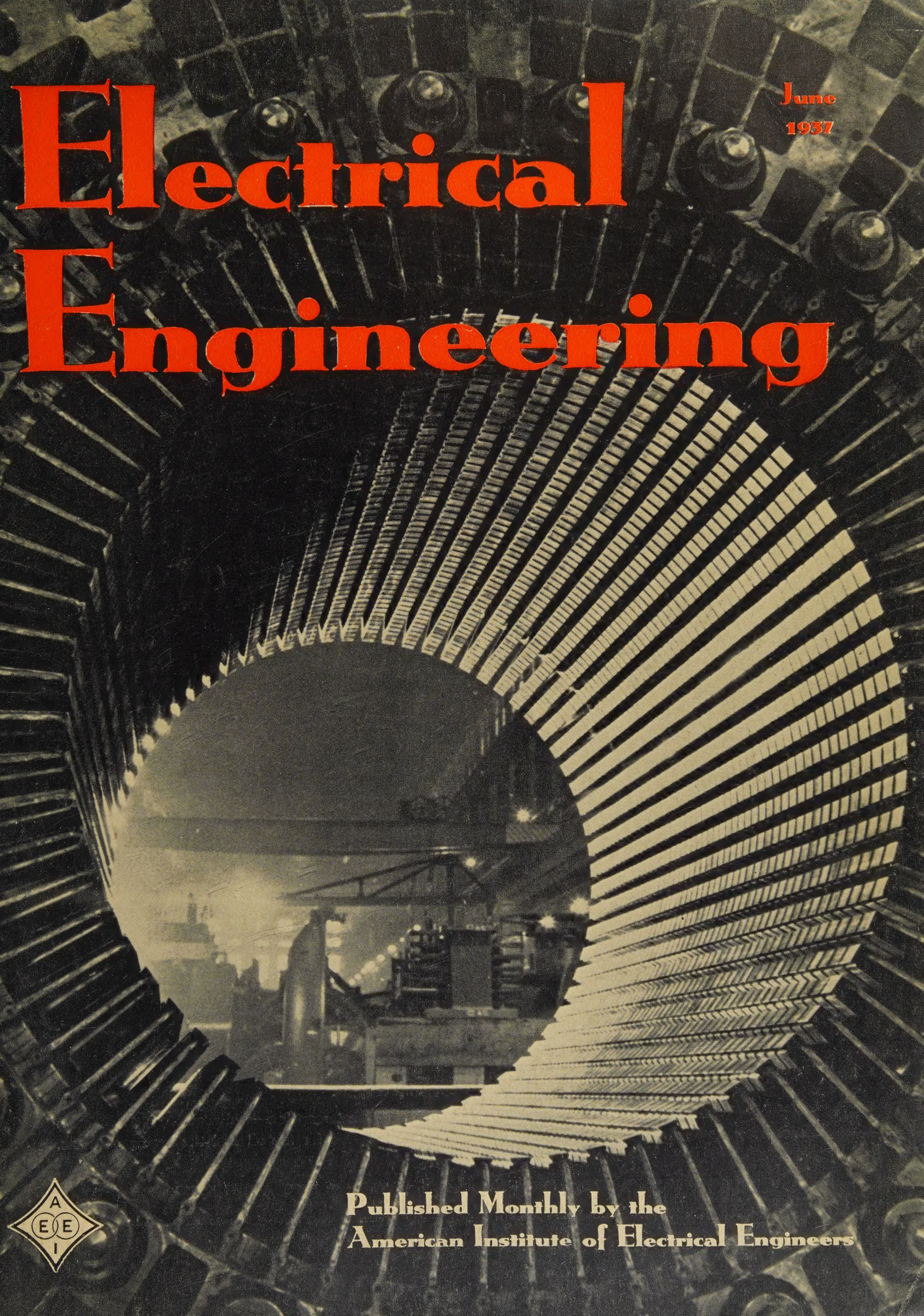
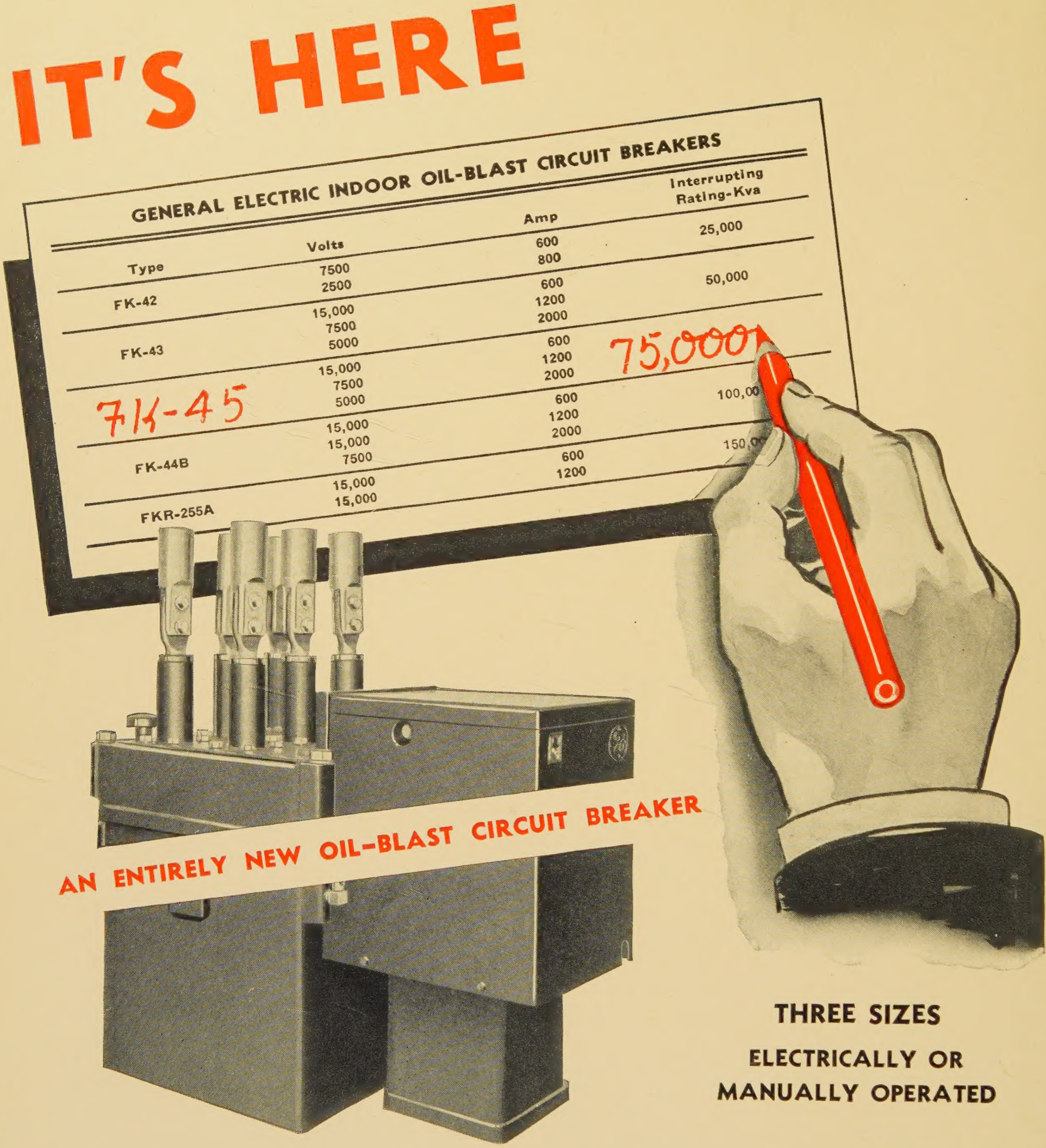
# Electrical Engineering

June
1937



Published Monthly by the
American Institute of Electrical Engineers




THREE SIZES

ELECTRICALLY OR MANUALLY OPERATED

## YOU'LL FIND SOUND VALUES IN THIS NEW G-E CIRCUIT BREAKER

Standard breaker can be shipped ready for service—all important adjustments are made at the factory.

Silver-surfaced, current-carrying contacts—which means no oxidation troubles.

Duplex butt-pressure-type arcing contacts—extremely long service here.

Strong Herkolite bushings, moisture-proof and unbreakable.

Oil-blast interruption—which means fast operation and long life for the oil and the arcing contacts.

890-35

# GENERAL ELECTRIC

# Electrical Engineering

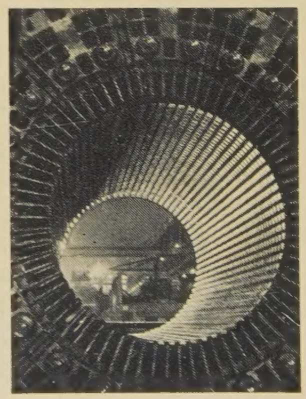
Registered U. S. Patent Office

## for June 1937—



### The Cover

A view, through the stator of a turbogenerator, of the Allis-Chalmers plant at Milwaukee, Wis., which may be visited by attendants at the Institute's 1937 summer convention



©

VOLUME 56 NUMBER 6

Published Monthly by the

**American Institute of Electrical Engineers**

(Founded 1884)



Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

# High Lights

**Radiobroadcasting.** Although radiobroadcasting stations in the United States operate on frequencies assigned so as to provide service to listeners throughout the country, practical limitations make impossible good reception on every one of the 100 frequency channels in the band of medium wave lengths for any one listener (*pages 666–70*). Frequencies of 30 or more megacycles per second have certain characteristics that make them particularly suitable for local broadcasting, and essential for television with present standards, but working frequencies in this region by no means are unlimited. Because such waves are limited in range almost to optical paths, they are unlikely to replace the medium-frequency waves now used for broadcasting over large areas (*pages 662–6*).

**Vibration.** Increasing the speed of machines imposes upon the engineer the necessity for seeking some means of reducing the amount of noise and vibration transmitted to the structures in which the machines are housed. Vibration isolation is one way of accomplishing this (*pages 735–8*). Instruments for precision measurement of vibration must measure amplitude, velocity, and acceleration. Fundamental requirements in the design of a general-purpose measuring instrument determining the useful frequency range, accuracy, amplitude range, and effect of the instrument on the vibrating body (*pages 706–10*).

**Insulation Co-ordination.** For several years a joint committee of Edison Electric Institute and National Electrical Manufacturers Association has been considering the subject of insulation co-ordination. As a result, basic impulse insulation levels now have been agreed upon, which constitutes the first step in the program (*pages 712–14*). A subcommittee has studied the factors that caused divergence in flashover values obtained by different commercial laboratories for the same test piece on impulse testing, and impulse and 60-cycle flashover values for rod gaps and insulators now have been agreed upon (*pages 711–12*).

**Recovery Voltages.** Determination of circuit recovery voltages for many different system conditions by actual tests is expensive and limited in scope. The voltages may be determined by analytical methods, which cannot consider all factors without becoming extremely complex, or by reproducing the system in miniature on an a-c calculating board and actually measuring the desired quantities (*pages 695–705*).

**Distribution Protection.** Investigation of the requirements of distribution systems for protection against surges shows that protectors should have a discharge capacity of 100,000 amperes, although a lower value may be satisfactory, and that a high degree of protection may be obtained in voltage classes up to 13.8 kv with a ratio of 9 to 1 for the protective-device discharge voltage and normal-frequency voltage (*pages 683–8*).

**Transformer Insulation.** For many years the transformer subcommittee of the AIEE committee on electrical machinery has been developing standards for the insulation strength of transformers. Impulse testing of insulation is one of the recent developments, and now the expression of impulse strength in terms of kilovolts instead of gap spacing is authorized (*pages 749–54*).

**Insulation Levels.** Insulation levels of transformers and other power system equipment should be selected according to the performance of the protective equipment such as lightning arresters and gaps; the level selected must be above the maximum surge voltage presumed to be allowed by the protective device on a volt-time basis over the range of time selected (*pages 677–82*).

**Security of Engineering Employment.** Data supplied by some 35,000 engineers shows that the degree of economic security among professional engineers, as evidenced by possession of an employment contract covering some period of time, or by pension privileges, is negligible (*pages 655–61*).

**Insulation Co-ordination.** Economy and the protection of service and equipment are the objectives of insulation co-ordination. Many data on the insulation strength of major equipment and protection available have been collected and are presented in graphical form in this issue (*pages 715–20*).

**Spill Gaps.** Theory and performance of spill gaps for the protection of electric circuits and equipment from lightning, together with a discussion of the selection of insulation levels co-ordinated with this type of protection, are presented in this issue (*pages 689–94*).

**Section and Branch Report.** The annual report of the Section and Branch activities for 1936–37 show that 621 meetings were held by AIEE Sections during the year, 81 more than during the preceding year; Student Branches held 1,363 meetings, by far the most ever held in a fiscal year (*pages 762–5*).

**District Meeting at Buffalo.** Active discussions on electrical equipment for steel mills and power system operation featured the Institute's North Eastern District meeting held recently at Buffalo, N. Y. The meeting included also a Student Branch convention (*pages 758–61*).

**Rotor Balancing.** Small gyro rotors such as are used in airplane flight instruments require balancing in production at speeds of 30,000 or 40,000 rpm. A machine using electrical means to detect unbalance is replacing older methods (*pages 729–34*).

**Oil-Filled Cables.** Improvements in oil-filled cable and associated equipment, have made possible economy and comparatively simple layout for about 100 miles of 66-kv oil-filled single-conductor cable now being installed in Chicago, Ill. (*pages 739–48*).

**Development of Standards.** The AIEE, with its technical committees covering all phases of the electrical art, many of which have active subcommittees, has an ideal setup for the development of material for electrical standards (*pages 653–4*).

**Prize Awards.** National prizes for technical papers presented at Institute meetings during 1936 have been awarded. Prize awards also have been announced by some of the Districts (*page 756*).

**Cathode-Ray Oscillograph.** A historical review of advances in the design of high-speed cathode-ray oscillographs, and a description of a new type of oscillograph, are included in this issue (*pages 721–8*).

**AEC Patent Report.** Action taken by the committee on patents of American Engineering Council during the year 1936 is summarized in the committee's annual report (*pages 766–7*).

**Noninflammable Insulating Oils.** A new type of synthetic insulating oil that obviates several of the problems heretofore associated with the use of mineral oil for insulation has been produced (*pages 671–6*).

**Summer Convention.** Final plans for the Institute's 1937 summer convention to be held at Milwaukee, Wis., June 21–25, are practically complete (*page 755*).

**New Members-for-Life.** Since June 1936, 92 members of the AIEE have become members-for-life (*page 757*).

Statements and opinions given in articles and papers appearing in Electrical Engineering are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ Electrical Engineering is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index;* abstracted monthly by *Science Abstracts* (London).  Number of copies this issue—19,800.

# Electrical Engineering

Published Monthly by

American Institute of Electrical Engineers

FOUNDED 1884

VOLUME 56, NO. 6 ▼ ▼ ▼ JUNE 1937


# What Institute Sections Are Doing

## —A Message From the President

FROM my limited viewpoints, a primary activity of other Sections is enthusiastically to receive and delightfully entertain the president. At those meetings where the president was an invited guest, but not the primary speaker, there was the greatest opportunity to learn what the Section was doing "to advance the theory and practice of electrical engineering, and the allied arts and sciences, and to maintain a high professional standing among the members." A meeting each year with a national officer or officers is most desirable, not only that the Section may learn of national activities, but even more that the national officers may be informed as to the Section's viewpoints. Several times this year, the president joined in a luncheon meeting with a Section's executive committee. These meetings were very profitable.

Undoubtedly, the most important factors in a Section's success are the enthusiasm and devotion of the Section's officers. Service to the profession appears to hold the strongest appeal for a representative electrical engineer, and the energy and time devoted to Section affairs by the Section officers is astonishing. Those Sections where this spirit is diffused most widely among the membership are certainly the most successful. Many Sections hold an executive committee meeting prior to each Section meeting, and with excellent results.

I have stressed the opportunity open to the Section to participate in national Institute affairs by nominating one or more members for appointment to the national committees, and by submitting at least one technical paper for publication in ELECTRICAL ENGINEERING. Several Sections have embraced this opportunity. In several cities I have been impressed when I learned that the program for the succeeding year was completely planned prior to the first of July. This practice permits the completion of arrangements for the speakers during the summer months, and further permits the program to be printed and distributed at the first fall meeting of the Section. When the program is so arranged, it is well balanced, best meeting the needs of the various members. If Section finances permit, the membership roster may be combined effectively with program announcements. Those Sections which are following this practice testify to its success.

Usually 9 meetings are held, and integrating the information I have secured throughout my trips, the following seems to be a good classification as to the types of meetings held: 3 meetings are addressed by out-of-Section speakers on recent developments in the field of electrical engineering; 2 inspection trips to local plants, with a short paper by an engineer connected with the plant, outlining what may be observed on the trip; 1 meeting with a paper by a member of the Section on some developments in electrical engineering; 1 meeting attended by a national officer or officers; 1 meeting with a local Student Branch (if there is a Branch in the city or the vicinity); 1 social meeting.

This division of the program has not provided any meeting relating to the broad interest of the engineer beyond his primary professional activity. Such a meeting might replace one of the meetings addressed by a local speaker, and be arranged as a joint meeting with other groups of engineers in the same city or locality. All Sections testify to the difficulty of getting enough speakers from outside the Section to cover all the desired meetings, and those which have developed the practice of securing local speakers testify to the success of this plan. Often the members are much more interested in papers relating to technical activity in their own locality than in those having no bearing on their particular professional interests.

Several Sections sponsor addresses on semi-scientific subjects having a popular appeal, not necessarily related to electrical engineering. At such a meeting it is essential to have an outstandingly interesting speaker; in some places where this plan is followed, the meetings are self-supporting. It seems to me that such a plan is quite con-

sistent with the fundamental purpose of the Institute.

Among the most interesting meetings I have attended, have been those where a Section joined with a local Student Branch. In some cases the technical papers have been presented by members of the Branch. These meetings were well attended by the older Institute members who were glad to have an opportunity to co-operate with the young engineers in training, and to encourage their professional development. In one instance, several neighboring Branches joined in an inspection trip in the morning, were entertained at lunch, held an all-afternoon technical meeting, with 6 Branch papers, and joined with the Section in a dinner followed by an address. In a Western city, an interesting custom has been developed. Each of several devoted Institute members pledged themselves to entertain a Branch member at one of the Section meetings during the year. This resulted in 2 or 3 Branch members being present at each Section meeting as individual guests of some of the older engineers. I talked to some of the student guests, and they were very strong in their expressions of appreciation. I recall another outstanding type of Section meeting where the members of the Section are quite widely distributed, and have only 4 meetings a year; but each meeting starts at 2:30 and continues all afternoon and evening. Papers are presented by both Enrolled Students and members, the total number of papers being 6 or 8. Some members drive between 150 and 200 miles to attend, but those from the more distant points are unable to stay for the evening sessions.

From my observations, the best meeting is likely to be that in which there is the most discussion. Anything that can be done to stimulate discussion is desirable. In one city, the author requested 3 or 4 acquaintances to discuss his paper. Usually it is necessary for only 3 or 4 men to start the discussion and a very wide discussion results. Where 2 or more Sections are fairly close together, joint meetings are inspiring. Such a joint meeting might be preceded by a golf match in the afternoon, both Sections joining in dinner, followed by a technical session. Such a plan permits of a larger audience for some outstanding speaker from outside the Sections participating.

If 2 neighboring Sections each plan their programs considerably in advance, it is possible to arrange for one speaker to address the 2 Sections on succeeding evenings. Such an idea has been under discussion for years, but actually is being applied successfully to only a limited extent. One somewhat remote Section has considerable difficulty in securing outside speakers and has adopted the practice of asking their own members to review the English technical publications and present a digest on one or 2 of the most important contributions.

From all quarters of the country, I have learned that inspection trips are very popular and are largely attended. More meetings of this character are undoubtedly desirable.

I feel that there should be many more members of the Institute among those electrical engineers connected with companies using electric power and electrical equipment, but manufacturing other products. The engineers of such companies desire meetings and papers recording experience with the application of electricity and electrical equipment. It is my belief that if the technical committees would develop more papers of interest to this group of engineers, the organization would be rendering a service that would be greatly appreciated and would stimulate interest. A few of the Sections are holding meetings with this group of engineers particularly in mind. "Application" papers are usually of a broad general interest.

Several of the Sections have a monthly or quarterly publication, recording the activities and plans of the Section. The expense is not very great, and the results are good.

In one or 2 Sections, I find a committee covering the broad activities of the engineer. Each Section may be interested in organizing such a committee. I have observed that the most successful Sections are usually the most social Sections. I am not quite certain as to cause and effect, whether they are most social because they are most successful, or whether they are most successful because they are the most social. Some very light and inexpensive refreshments after meetings do add to sociability. In the West where many attend from a distance, a dinner preceding the meeting is usually held. If it is possible to develop the idea that attendance at the dinner is not necessary, but open to all, good results will follow.

Many Sections have organized specialized technical groups, holding additional meetings. Interest has been good and the meetings well attended. I have heard the statement made that it is not possible to organize such a group in a particular Section because there is not any very specialized industry. To such a Section I would suggest studying the list of technical committees to see if there is not some activity of unusual interest in that locality. For example, it might be desirable in some Sections to organize a general power application technical group, in others a technical education group.

I found one Section giving a great deal of consideration to sponsoring meetings for the benefit of men interested in electrical work, but not necessarily eligible for membership in the AIEE. It certainly seems quite in accord with the fundamental purposes of our organization, that the Institute Section should take the lead in arranging for speakers, and furnishing a meeting place where all the men interested in electrical work could receive information of value to them.

In a Western city, I heard a discussion as to whether it might not be possible to broadcast a Section meeting over short-wave radio. Several members of the Section had operator's licenses. This plan might not be consistent with governmental regulations, but deserves investigation.

One chairman told me that 3 or 4 years ago they wondered what they might do to carry on effectively the work of the AIEE. They decided that no more important meeting could be held than one that would offer the opportunity to every Section member to suggest what he thought might be done. This meeting was held, and since that time the principal problem has been to cover effectively all the suggestions that were made.

Several times I heard the thought expressed that each Section should have a committee on engineering co-operation with other engineering groups in the same city or locality. It seems very desirable that the engineering

activities covering all branches of the profession should be co-ordinated. It certainly is true that many of the questions which should interest the engineer are equally interesting to all types of engineers, whether they be mechanical, civil, electrical, or otherwise. No Institute member should forget the reference in Article 1 of our Constitution to "the allied arts and sciences."

It is my hope that Chairman W. H. Timbie and all members of the Sections committee will sponsor a paper to be printed in ELECTRICAL ENGINEERING next year on the subject "What The Other Sections Are Doing."

# Development of Standards Material

## A discussion of the responsibility of AIEE committees in aiding the development of electrical standards

By V. M. MONTSINGER
FELLOW AIEE

H. E. FARRER
ASSOCIATE AIEE

FOR an industry that manufactures and uses as large a variety of apparatus as the electrical industry, the problem of the development of standards is a tremendously important one. The purposes of standards are 2-fold: In the first place, they aid in the manufacture of products that are more uniform; in the second place, they form a basis that enables purchasers to obtain bids for new apparatus on a comparable basis.

For many years one of the chief duties of the AIEE has been the formulation and maintenance of standards for all kinds of electrical apparatus and machinery. In the past, purchasers of electrical apparatus have based their purchasing specifications largely on AIEE Standards.

So long as the Institute was the principal body in formulating electrical standards, the duties of its members and committees engaged in standardization were clearly understood. When, because of rapid developments in the art, other organizations—the National Electrical Manufacturers' Association, the Edison Electric Institute, the National Bureau of Standards, the American Society for Testing Materials, and others—found it necessary to formulate standards of their own, usually consisting largely of material not considered within the scope of AIEE Standards, it became desirable to co-ordinate the work of standardization under one central agency so constituted as to assure general acceptance. In 1918, therefore, on the basis of a plan formulated by the AIEE co-operating with the other national engineering societies, the Bureau of Standards, and others, the American Standards Association, or as it then was called, the American Engineering Standards Committee, was established. This organization grew rapidly, and under its procedure were developed many standardization projects outside the electrical field. Further to expedite and correlate electrical standardization under ASA procedure, the Electrical Standards Committee was created. The principal electrical standardization groups have representatives on this electrical standards committee, thus giving assurance that when a standard has the approval of the electrical standards committee it practically has the approval of the entire electrical industry and readily is accorded the status of American Standard by final action of ASA.

With this new setup, the question naturally arises as to what are the duties and responsibilities of the AIEE committees in the formulation and maintenance of electrical standards. The opinion seems to have developed that the ASA has taken over the standards-making obligation and that the Institute no longer has an active duty in the development of standards. This is an erroneous impression which should not exist, and this article aims to show why it still is the Institute's privilege and duty to develop standards material for submission to the ASA through the electrical standards committee. The ASA Council then will decide whether the material is ready for adoption as an American Standard, or whether it is desirable to organize a sectional committee to which it may be referred, with other pertinent material, for review and revision in order to assure general acceptance.

The Institute still has an ideal setup for the development of standards material, namely, the technical committees, covering all phases of the electrical art, many with active subcommittees. The Institute also has means for immediate and wide circulation of information and

Written especially for ELECTRICAL ENGINEERING.

V. M. MONTSINGER is chairman of the AIEE standards committee and has been a member of that committee since 1928; he has also been a member of the AIEE committee on electrical machinery since 1926 (chairman 1934–36). He was chairman of the Institute's Pittsfield Section, 1923–33, and has served on advisory committees of the International Electrotechnical Commission. He is the author of many papers on the subject of transformers. Mr. Montsinger is research engineer of the General Electric Company, Pittsfield, Mass.

H. E. FARRER is assistant to the national secretary of the AIEE; he has served as secretary of the AIEE standards committee since 1923, and has been intimately associated with the work of the standards committee since that time.

data on proposed new developments. This is essential and valuable in keeping the Standards up-to-date and in avoiding long delays in final approval of revisions and of new developments.

To illustrate, the development of a typical new Standard is outlined: Some 6 or 7 years ago the electrical industry decided that consideration should be given to the development of a standard covering impulse testing of transformers. This work was assigned to the AIEE standards committee and by them to the AIEE electrical machinery committee. The machinery committee requested its transformer subcommittee, which was composed of representatives of both operators and manufacturers, to develop the new standards.

Before the standard on impulse tests could be proposed, much research work had to be done in both the laboratory and in the field. As this work went on, the results were published from time to time in ELECTRICAL ENGINEERING. This proved very helpful to the subcommittee. So much ground work had to be done that the subcommittee worked on the problem for 3 or 4 years before standards material could even be proposed, but as soon as the Proposed Standards on impulse testing were published in 1933 the industry accepted them. However, due to the rapid advances in the art and to the accumulation of new data, thought on the subject was not sufficiently crystallized until just recently to justify publication as Tentative American Standards. Publication in this form within the next few months is planned.

Had this work not been assigned to the AIEE, impulse testing of commercial transformers would have been seriously delayed—until the Standards were officially approved. In other words, due to the setup in the AIEE committees, together with the means for obtaining wide publicity for the work of the transformer subcommittee, the industry has been able to make use of the proposed standards material on impulse testing while it was in the developmental stage.

In addition to the formulation of new standards material on impulse testing, the AIEE transformer subcommittee during this time recommended several fundamental changes in the standards, all of which were accepted by the industry as soon as published.

Several years ago, it was decided to seek approval as American Standards for the AIEE Transformer Standards and at the same time to pass along the work done by the transformer subcommittee on proposed changes in those standards. After obtaining approval by the electrical machinery committee and the standards committee, the transformer standards and proposed revisions were turned over to the ASA for consideration as American Standards. To obtain such approval the ASA organized the sectional committee on transformers, *C*-57. While a great deal of work has been done by the sectional committee in getting together the material covered not only in the AIEE standards, but in the standards of other societies to be combined with them, no changes of a fundamental nature have been made by the sectional committee without having them first considered and approved by the AIEE. This is quite logical because, as pointed out hereinbefore, the ASA has no means of getting proposed fundamental changes before the industry until the standards are given final approval. This question of informing the industry of proposed changes in the standards is well illustrated in this case by the publication in ELECTRICAL ENGINEERING since 1933 of 2 reports by the AIEE transformer subcommittee. In many instances, however, it has proved more advantageous to follow a somewhat different procedure; that is, to have the reports published by the standards committee in pamphlet form for general distribution, with an announcement of their availability published in ELECTRICAL ENGINEERING.

Photo courtesy Ohio Brass Company

**A transmission line of Fabulosa Mines Consolidated, Bolivia, S. A., high in the Andes Mountains. The peak in the background is Mt. Huayna Potosi, elevation 20,000 feet. The span is 350 meters long and consists of number 4 steel-reinforced aluminum cable**

The procedure followed by the AIEE and ASA in transformer standardization work is not limited at all to transformer problems, but can and should be followed by other committees working on standards for other types of apparatus. In other words, it is the very definite responsibility and duty of the AIEE technical committees to prepare and formulate standards material, developing it to a point where it is satisfactory to the industry. The current procedure then is for an AIEE technical committee to pass this work on to the AIEE standards committee. The standards committee then approves the material, if satisfactory, either for publication in report form, or for transmittal to the ASA for consideration and approval as American Standards.

There may be exceptions to this procedure, in which event action should be based on the conditions applying to the particular situation.

# Security of Engineering Employment

**Data obtained from 35,559 engineers by the United States Bureau of Labor Statistics in its survey of the engineering profession indicate that the degree of economic security among professional engineers, as evidenced by possession of an employment contract covering some period of time, or by pension privileges, was negligible. This is the fourth* in a series of articles reporting the results of the Bureau's survey.**

PRIOR to the onset of the depression in 1929, only nonprofessional workers were primarily concerned with the stability and security of employment. The effects of the depression years, however, were such as to bring about a quickening of interest in the subject of economic security even among professional workers. Because of this, a series of questions relating to this subject was incorporated into the Bureau's study of the engineering profession. Data were requested concerning the employment and separation contract, pension privileges, and the medium used to obtain a position, also whether or not the engineer reporting was under civil service, and what his status was with regard to patent rights.

The present article is based upon data supplied by 35,559 engineers who reported the field of engineering engaged in and who had an engineering job in December 1934.[1] Their reports indicate that 68.4 per cent of all professional engineers used personal contacts and recommendations to obtain their jobs. Those who used this medium, together with those who obtained their positions through the civil service, formed nearly $^4/_5$ of all reporting.

The degree of economic security among professional engineers, as evidenced by possession of an employment contract covering some period of time, or by pension privileges, was negligible.

In general, there appears to be little restriction upon professional engineers with regard to patent rights to inventions made by them. The extent of restriction, however, depended largely upon the engineer's field of employment and the type of work in which engaged.

## Means Used to Obtain Employment

The data furnished by engineers concerning the medium through which they obtained employment are presented in table I. These figures demonstrate that for the engineering profession as a whole, placement was not the function of any particular organization. The vast majority of professional engineers obtained their jobs through personal contacts and recommendations. This was the means used to find the position held in 1934 by no less than 68.4 per cent of the 35,559 engineers who also reported the field of engineering activity in which they were engaged. This medium of employment was reported by $^3/_4$ of the chemical, electrical, and mining and metallurgical engineers, and by slightly more than 70.0 per cent of the mechanical and industrial engineers, but by only 61.7 per cent of the civil engineers. The civil engineers, however, found more positions through civil service agencies; in fact, 2,941, or 80.0 per cent, of the 3,706 engineers who were classified under this medium were civil engineers. This is further emphasized by a consideration of the data for the 5 professional classes. Of the engineers who had engineering jobs in December 1934, 19.8 per cent of the civil engineers stated that these were found through the civil service, whereas among the remaining 4 professional classes, the range was from only 2.5 per cent for the chemical and ceramic to 4.6 per cent for the mining and metallurgical engineers.

It may be noted, however, that personal contacts and recommendations, together with civil service, accounted for 74.2 per cent of the mechanical and industrial engineers. For each of the remaining professional classes, these 2 mediums covered approximately $^4/_5$ of their respective totals, ranging from 78.4 per cent of the chemical and ceramic to 81.5 per cent of the civil engineers. Mechanical and industrial engineers reported relatively higher percentages of jobs obtained through an engineering society, a private employment agency, and newspapers. The most significant differences, however, will be noted for "medium not reported" and "any other medium." Thus, only in the case of civil, and mining and metallurgical engineers did "any other medium" embrace smaller proportions than those classified under "medium not reported." For the other 3 professional classes, this condition was reversed. Any other medium may well include a substantial number placed through their colleges, a point not covered in the questionnaire and one likely to affect the percentage noted in this classification.

Although the percentage distributions for the remaining avenues to employment do not embrace large numbers of each professional class, relatively they do present some striking contrasts. Only 2.4 per cent of all engineers reported that they obtained their positions through an engineering society. Some 3.7 and 2.7 per cent, respec-

---

* An article prepared by Andrew Fraser, Jr., of the Division of Hours, Wages, and Working Conditions, Bureau of Labor Statistics, United States Department of Labor, which article was published in the May 1937 issue of *Monthly Labor Review*. Articles reporting other phases of this survey were published in ELECTRICAL ENGINEERING as follows: "Professional Aspects of Engineering Education," August 1936, pages 863–7; "Unemployment in the Engineering Profession," February 1937, pages 216–23; "Employment in the Engineering Profession," May 1937, pages 524–31. A detailed report of the survey will be published later in bulletin form by the Bureau of Labor Statistics.

1. The numbers reported in this article as engaged in engineering work in December 1934 cannot be compared with those shown in the discussion of employment. The former were derived from all of the 35,890 engineers who reported the field of engineering in which they were engaged. The discussion of employment dealt with all those older engineers who reported in the 3 years 1929, 1932, and 1934, and all 1930–32 engineers who reported in the years 1932 and 1934. The grand total, including the 1933–34 engineers, was 35,675.

Of the 35,890 engineers who gave income data in their special field, 331 did not report the year of their birth. Hence, 35,559 constitutes the base for all subsequent relationships with field of engineering engaged in. But 1,458 of these engineers did not report as to type of work engaged in, and hence 34,101 was used as a base figure for all subsequent relationships with functional classification.

tively, of the mechanical and industrial, and mining and metallurgical engineers were so classified. For the 3 remaining professional classes, the percentages ranged from 1.4 to 1.9. Despite the fact that so few engineers reported an engineering society as their employment medium, it must be recognized that such societies are an important factor in obtaining employment for professional engineers It is obvious that through their members there must inevitably be a pooling of information on employment prospects, both locally and nationally. Furthermore, the officials of the various societies are kept in close touch with local and national employment conditions as a result of their meetings and conventions; but such appointments as are made would depend rather upon personal contacts and recommendations than upon contacts made through the society's employment service. The fact, therefore, that only 2.4 per cent of all engineers reported the engineering society as their medium of employment must be interpreted in the light of these conditions.

**Table I. Distribution of All Engineers Reporting Medium of Obtaining Employment, by Professional Class, at End of 1934**

| Medium Used to Obtain Employment | Engineers Utilizing Each Specified Medium: All Professional Classes | Chemical and Ceramic Engineers | Civil, Agricultural, and Architectural Engineers | Electrical Engineers | Mechanical and Industrial Engineers | Mining and Metallurgical Engineers |
|---|---|---|---|---|---|---|
| | **Number** | | | | | |
| All mediums | 35,559 | 2,538 | 14,861 | 6,816 | 9,833 | 1,511 |
| Personal contacts and recommendations | 24,312 | 1,927 | 9,179 | 5,106 | 6,960 | 1,140 |
| Civil service | 3,706 | 63 | 2,941 | 289 | 343 | 70 |
| Engineering society | 841 | 36 | 274 | 130 | 360 | 41 |
| Private employment agency | 576 | 49 | 113 | 112 | 285 | 17 |
| Newspapers | 567 | 27 | 152 | 120 | 255 | 13 |
| Technical journals | 363 | 54 | 142 | 64 | 85 | 18 |
| United States Employment or Reemployment Service | 264 | 7 | 190 | 14 | 46 | 7 |
| Other public employment service | 268 | 15 | 169 | 26 | 54 | 4 |
| Any other medium | 2,551 | 259 | 706 | 655 | 849 | 82 |
| Medium not reported | 2,111 | 101 | 995 | 300 | 596 | 119 |
| | **Per Cent** | | | | | |
| All mediums | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Personal contacts and recommendations | 68.4 | 75.9 | 61.7 | 75.0 | 70.7 | 75.4 |
| Civil service | 10.4 | 2.5 | 19.8 | 4.2 | 3.5 | 4.6 |
| Engineering society | 2.4 | 1.4 | 1.8 | 1.9 | 3.7 | 2.7 |
| Private employment agency | 1.6 | 1.9 | 0.8 | 1.6 | 2.9 | 1.1 |
| Newspapers | 1.6 | 1.1 | 1.0 | 1.8 | 2.6 | 0.9 |
| Technical journals | 1.0 | 2.1 | 1.0 | 0.9 | 0.9 | 1.2 |
| United States Employment or Reemployment Service | 0.7 | 0.3 | 1.3 | 0.2 | 0.5 | 0.5 |
| Other public employment service | 0.8 | 0.6 | 1.1 | 0.4 | 0.5 | 0.3 |
| Any other medium | 7.2 | 10.2 | 4.8 | 9.6 | 8.6 | 5.4 |
| Medium not reported | 5.9 | 4.0 | 6.7 | 4.4 | 6.1 | 7.9 |

The securing of employment through newspapers and technical journals was reported by 1.6 and 1.0 per cent, respectively, of all engineers making returns. It will be noted however that, relatively, electrical and mechanical and industrial engineers found more jobs through newspapers than did any of the other professional classes; this medium was reported by 1.8 per cent of the electrical and 2.6 per cent of the mechanical and industrial engineers, whereas, among the other classes the highest percentage was 1.1. On the other hand, technical journals as a medium of employment were of more assistance to chemical and ceramic engineers (2.1 per cent); among the remaining professional classes percentages ranged from 0.9 to 1.2.

Private employment agencies were used by only 1.6 per cent of all engineers reported. When considered together, the 2 public employment agencies embraced approximately the same proportion, namely, 1.5 per cent. A similar comparison among the 5 professional classes showed that, relatively, public agencies were of more importance to civil engineers, of whom 2.4 per cent so reported, whereas the next highest percentage was 1.0 per cent for mechanical and industrial engineers. Only 0.8 per cent of the civil engineers used private employment agencies to obtain jobs, but 2.9 per cent of the mechanical and industrial engineers did so; for the remaining professional classes, the percentages ranged from 1.1 to 1.9 per cent.

## Economic Security in the Engineering Profession

A written contract of employment and pension privileges are 2 important criteria of economic security. The efficacy of any such schemes, however, depends to a marked extent upon the nature of the employment. This is demonstrated by a comparison of the data concerning economic security among professional engineers who reported being engaged in public engineering, personal service, and private engineering.

### Civil-Service Status

The importance of civil-service status as a factor in stability of employment is shown in table II. Despite the fact that, in all, 11,177 of the engineers reporting were in the employ of public authorities in December 1934, only 45.0 per cent reported being under civil service. The proportion of all engineers with civil-service status was 48.4 per cent for positions under the Federal Government, and for employment with state and county, and municipal and other public authorities, 36.1 and 45.6 per cent, respectively. This percentage under civil service of these engineers employed by the Federal Government was higher than in the 2 other public employments, despite the enormous increase in Federal Government employment by December 1934, because of the amount of temporary employment under the work-relief programs; it may be assumed that relatively few engineers so employed would be classified under civil service. Consequently, under normal circumstances, the proportion of all engineers under civil service with the Federal Govern-

ment would be higher than 48.4 per cent. With regard to the other 2 classes of public engineering, it may be recalled that the numbers of engineers so engaged remained comparatively stable over the period 1930–34. Hence, the proportions reported being under civil service are representative of the situation.

The relative proportions of each professional class under civil service differed very markedly among the 3 classes of public engineering employment. The smallest range occurred in Federal positions—from 45.1 per cent for electrical engineers to 62.0 per cent for mining and metallurgical engineers. These 2 professional classes also constituted the extremes of the range of the proportions embraced by municipal governments, but in reverse order. Thus, of the mining and metallurgical engineers in municipal employment, 30.4 per cent, and of the electrical engineers, 57.1 per cent, had civil-service status. Relatively, the smallest numbers of each professional class under civil service were found in state and county governments. This is best exemplified by the comparative data for civil engineers; of their number 47.9 and 43.8 per cent, respectively, in Federal and municipal employments but only 38.0 per cent in state and county positions had civil-service status. But since the civil engineers comprised approximately 80.0 per cent of the 5,038 engineers under civil service, obviously such a status is a significant contributory factor to the stability of employment.

**Table II. Distribution of All Engineers Reporting as to Civil-Service Status, by Field of Activity and Professional Class, at End of 1934**

| Field of Employment and Professional Class | Number | | | | Per Cent | | | |
|---|---|---|---|---|---|---|---|---|
| | Total | Without Status | With Status | Not Reporting | Total | Without Status | With Status | Not Reporting |
| Federal Government | 4,649 | 2,084 | 2,250 | 315 | 100.0 | 44.8 | 48.4 | 6.8 |
| Chemical and ceramic | 74 | 22 | 44 | 8 | 100.0 | 29.7 | 59.5 | 10.8 |
| Civil, agricultural, and architectural | 3,620 | 1,649 | 1,734 | 237 | 100.0 | 45.6 | 47.9 | 6.5 |
| Electrical | 306 | 143 | 138 | 25 | 100.0 | 46.7 | 45.1 | 8.2 |
| Mechanical and industrial | 549 | 240 | 272 | 37 | 100.0 | 43.7 | 49.6 | 6.7 |
| Mining and metallurgical | 100 | 30 | 62 | 8 | 100.0 | 30.0 | 62.0 | 8.0 |
| State and county governments | 4,438 | 2,487 | 1,604 | 347 | 100.0 | 56.1 | 36.1 | 7.8 |
| Chemical and ceramic | 37 | 30 | 3 | 4 | 100.0 | 81.1 | 8.1 | 10.8 |
| Civil, agricultural, and architectural | 4,044 | 2,203 | 1,535 | 306 | 100.0 | 54.4 | 38.0 | 7.6 |
| Electrical | 134 | 91 | 33 | 10 | 100.0 | 67.9 | 24.6 | 7.5 |
| Mechanical and industrial | 170 | 123 | 28 | 19 | 100.0 | 72.3 | 16.5 | 11.2 |
| Mining and metallurgical | 53 | 40 | 5 | 8 | 100.0 | 75.5 | 9.4 | 15.1 |
| Municipal governments | 2,090 | 1,028 | 952 | 110 | 100.0 | 49.1 | 45.6 | 5.3 |
| Chemical and ceramic | 54 | 28 | 23 | 3 | 100.0 | 51.8 | 42.6 | 5.6 |
| Civil, agricultural, and architectural | 1,617 | 829 | 709 | 79 | 100.0 | 51.3 | 43.8 | 4.9 |
| Electrical | 238 | 88 | 136 | 14 | 100.0 | 37.0 | 57.1 | 5.9 |
| Mechanical and industrial | 158 | 70 | 77 | 11 | 100.0 | 44.3 | 48.7 | 7.0 |
| Mining and metallurgical | 23 | 13 | 7 | 3 | 100.0 | 56.6 | 30.4 | 13.0 |

### The Employment Contract

For the engineering profession as a whole, the data in table III clearly evidence a lack of economic security in terms of a written contract which would secure employment over a substantial period of time. In all, only 3,169, or 8.9 per cent, of the 35,559 engineers who reported employment in an engineering field[2] were covered by a written contract. Of these, some 0.8 per cent had a contract for less than 1 year, 3.5 per cent a contract for between 1 and 2 years, and only 0.9 per cent for 2 years or more. Engineers who did not report as to period of contract formed 3.7 per cent of the whole. No less than 91.1 per cent either answered "no" or did not furnish specific information.

Comparison of the positive returns on employment contract from all engineers in the 3 broad fields of engineering activity shows that use of the contract was most common in personal service—primarily education.

For engineers under contract in the personal-service field the most common contract period (reported by 25.6 per cent of the 2,778 engineers so engaged) was from 1 to 2 years. Some 4.0 per cent were under contract for periods of 2 years or longer. Although the corresponding percentages for public engineering were much lower than for personal service, they were higher than for private engineering. For employment contracts under 1 year, however, private exceeded public engineering (1.0 per cent, as against 0.5 per cent). Of all reporting engineers engaged in public engineering, 2.0 per cent had contracts for 1 and under 2 years, and 1.1 per cent for periods of 2 years and over. The corresponding percentages for private engineering were 1.4 and 0.5 per cent.

For the separate fields of activity under private engineering, relatively the largest proportion of engineers under contract in their jobs occurred in manufacturing, with 408, or 3.8 per cent, of the 10,888 reporting as so engaged. In the construction and extractive industries 3.0 and 2.0 per cent, respectively, had written contracts. The smallest proportions under contract were reported by engineers in the employ of public utilities or engaged in transportation (1.1 and 0.9 per cent, respectively). In public engineering, there was a marked contrast in contract status between Federal positions and those in the 2 other categories of public engineering. Thus, while only 2.3 per cent of the 4,649 reporting engineers in Federal employ were on con-

2. Throughout the whole of this discussion, only engineering employment is considered. Consequently, no cognizance has been taken of the economic security of engineers engaged in nonengineering employment.

**Table III. Distribution of All Engineers Reporting Employment Contract, by Field of Employment at End of 1934**

| Field of Employment | Number: Total | Number: Under Contract for— Under 1 Year | Number: Under Contract for— 1 and Under 2 Years | Number: Under Contract for— 2 Years and Over | Number: Under Contract, No Period Reported | Number: Not Reporting* | Per Cent: Total | Per Cent: Under Contract for— Under 1 Year | Per Cent: Under Contract for— 1 and Under 2 Years | Per Cent: Under Contract for— 2 Years and Over | Per Cent: Under Contract, No Period Reported | Per Cent: Not Reporting* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All fields | 35,559 | 295 | 1,234 | 330 | 1,310 | 32,390 | 100.0 | 0.8 | 3.5 | 0.9 | 3.7 | 91.1 |
| Private engineering | 21,604 | 212 | 298 | 99 | 637 | 20,358 | 100.0 | 1.0 | 1.4 | 0.5 | 2.9 | 94.2 |
| Construction | 3,437 | 32 | 63 | 12 | 113 | 3,217 | 100.0 | 0.9 | 1.8 | 0.3 | 3.3 | 93.7 |
| Extractive industries | 1,841 | 11 | 21 | 6 | 60 | 1,743 | 100.0 | 0.6 | 1.1 | 0.3 | 3.3 | 94.7 |
| Public utilities | 4,183 | 16 | 21 | 8 | 50 | 4,088 | 100.0 | 0.4 | 0.5 | 0.2 | 1.2 | 97.7 |
| Transportation | 1,255 | 5 | 4 | 2 | 17 | 1,227 | 100.0 | 0.4 | 0.3 | 0.2 | 1.4 | 97.7 |
| Manufacturing | 10,888 | 148 | 189 | 71 | 397 | 10,083 | 100.0 | 1.4 | 1.7 | 0.7 | 3.6 | 92.6 |
| Public engineering | 11,177 | 53 | 224 | 121 | 295 | 10,484 | 100.0 | 0.5 | 2.0 | 1.1 | 2.6 | 93.8 |
| Federal Government | 4,649 | 33 | 42 | 34 | 181 | 4,359 | 100.0 | 0.7 | 0.9 | 0.7 | 3.9 | 93.8 |
| State and county governments | 4,438 | 15 | 125 | 50 | 81 | 4,167 | 100.0 | 0.3 | 2.8 | 1.1 | 1.8 | 94.0 |
| Municipal governments | 2,090 | 5 | 57 | 37 | 33 | 1,958 | 100.0 | 0.2 | 2.7 | 1.8 | 1.6 | 93.7 |
| Personal service | 2,778 | 30 | 712 | 110 | 378 | 1,548 | 100.0 | 1.1 | 25.6 | 4.0 | 13.6 | 55.7 |

* Also includes those who reported "no," which number could not be separated in the tabulation.

tract, the proportion working on this basis for state and county, and municipal governments formed, respectively, 4.2 and 4.7 per cent of their grand totals.

The type of work in which engineers under contract were engaged is presented in table IV. In general, the distribution followed the same trend as shown in table III, that is to say, the largest groups had written contracts for periods from 1 and under 2 years. Table IV also confirms the previous finding that engineers engaged in teaching are relatively more secure with regard to employment than other members of the engineering profession: 33.8 per cent of their number reported written contracts for periods of from 1 to 2 years. Sales employments, next in order, had under contract for a similar period only 3.9 per cent of their 1,513 reporting engineers, and general administration and management only 2.3 per cent. Each of the other functional classes had less than 2.0 per cent. Even for the contract periods of 2 years and over, teaching covered 4.8 per cent of the total reported for this functional class. The next highest percentage, namely, 1.5, was reported for general administration and management. In no one of the remaining employments did the percentage of engineers with written contracts for 2 years and over exceed 0.8 per cent.

Thus, with regard to fields of activity or the functional classes within them, the engineering profession cannot be said to have any substantial security of employment provided through a written contract for a period of time. However, professional engineers are not generally restricted with regard to the seeking of employment similar to that in which they may be engaged. This is evidenced by a consideration of the data furnished by professional engineers concerning their separation-contract status (tables V and VI).

Only 1.4 per cent of all the reporting engineers stated that they were under a contract for a definite period of time during which they bound themselves not to seek similar employment. This included 0.8 per cent whose separation contracts were for less than 1 year, 0.2 per cent for a period of from 1 to 2 years, and 0.4 per cent for 2 years and over. Clearly, restrictions upon professional engineers with regard to new employment were few.

It may be noted in table V, however, that 2.1 per cent of the reporting engineers in personal service were under separation contracts for less than one year, whereas the proportion in extractive industries and manufacturing was 1.0 per cent each. The reason for the relatively greater use of the separation contract in personal service is not clear. In extractive industries and manufacturing, the use of secret processes probably makes necessary some

**Table IV. Distribution of All Engineers Reporting Employment Contract, by Type of Work Engaged in at End of 1934**

| Type of Work | Number: Total | Number: Under Contract for— Under 1 Year | Number: Under Contract for— 1 and Under 2 Years | Number: Under Contract for— 2 Years and Over | Number: Under Contract No Period Reported | Number: Not Reporting* | Per Cent: Total | Per Cent: Under Contract for— Under 1 Year | Per Cent: Under Contract for— 1 and Under 2 Years | Per Cent: Under Contract for— 2 Years and Over | Per Cent: Under Contract No Period Reported | Per Cent: Not Reporting* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All types | 34,101 | 288 | 1,196 | 311 | 1,236 | 31,070 | 100.0 | 0.8 | 3.5 | 0.9 | 3.6 | 91.2 |
| Design and research | 9,050 | 106 | 119 | 52 | 305 | 8,468 | 100.0 | 1.2 | 1.3 | 0.6 | 3.4 | 93.5 |
| Construction | 8,233 | 39 | 153 | 63 | 209 | 7,769 | 100.0 | 0.5 | 1.9 | 0.8 | 2.5 | 94.3 |
| Operation | 8,276 | 57 | 79 | 38 | 148 | 7,954 | 100.0 | 0.7 | 1.0 | 0.5 | 1.8 | 96.0 |
| Consulting | 2,146 | 26 | 30 | 11 | 80 | 1,999 | 100.0 | 1.2 | 1.4 | 0.5 | 3.7 | 93.2 |
| Teaching | 2,050 | 24 | 692 | 98 | 350 | 886 | 100.0 | 1.2 | 33.8 | 4.8 | 17.1 | 43.1 |
| Sales | 1,513 | 15 | 59 | 7 | 56 | 1,376 | 100.0 | 1.0 | 3.9 | 0.5 | 3.7 | 90.9 |
| General administration and management | 2,833 | 21 | 64 | 42 | 88 | 2,618 | 100.0 | 0.7 | 2.3 | 1.5 | 3.1 | 92.4 |

* Also includes those who reported "no," which number could not be separated in the tabulation.

### Table V. Distribution of All Engineers Reporting Separation Contract, by Field of Employment at End of 1934

| Field of Employment | Number: Total | Number: Under Contract for—Under 1 Year | Number: Under Contract for—1 and Under 2 Years | Number: Under Contract for—2 Years and Over | Number: Under Contract, No Period Reported | Number: Not Reporting* | Per Cent: Total | Per Cent: Under Contract for—Under 1 Year | Per Cent: Under Contract for—1 and Under 2 Years | Per Cent: Under Contract for—2 Years and Over | Per Cent: Under Contract, No Period Reported | Per Cent: Not Reporting* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All employments | 35,559 | 287 | 77 | 128 | 95 | 34,972 | 100.0 | 0.8 | 0.2 | 0.4 | 0.3 | 98.3 |
| Private engineering | 21,604 | 180 | 67 | 124 | 38 | 21,195 | 100.0 | 0.8 | 0.3 | 0.6 | 0.2 | 98.1 |
| Construction | 3,437 | 32 | 5 | 8 | 10 | 3,382 | 100.0 | 0.9 | 0.1 | 0.2 | 0.3 | 98.5 |
| Extractive industries | 1,841 | 19 | 1 | 2 | 4 | 1,815 | 100.0 | 1.0 | 0.1 | 0.1 | 0.2 | 98.6 |
| Public utilities | 4,183 | 16 | 2 | 2 | 4 | 4,159 | 100.0 | 0.4 | (†) | (†) | 0.1 | 99.5 |
| Transportation | 1,255 | 2 | | | 2 | 1,251 | 100.0 | 0.2 | | | 0.2 | 99.6 |
| Manufacturing | 10,888 | 111 | 59 | 112 | 18 | 10,588 | 100.0 | 1.0 | 0.5 | 1.0 | 0.2 | 97.3 |
| Public engineering | 11,177 | 50 | 3 | 2 | 26 | 11,096 | 100.0 | 0.4 | (†) | (†) | 0.2 | 99.4 |
| Federal Government | 4,649 | 16 | 1 | 2 | 8 | 4,622 | 100.0 | 0.3 | (†) | (†) | 0.2 | 99.5 |
| State and county governments | 4,438 | 27 | 1 | | 10 | 4,400 | 100.0 | 0.6 | (†) | | 0.2 | 99.2 |
| Municipal governments | 2,090 | 7 | 1 | | 8 | 2,074 | 100.0 | 0.3 | (†) | | 0.4 | 99.3 |
| Personal service | 2,778 | 57 | 7 | 2 | 31 | 2,681 | 100.0 | 2.1 | 0.3 | 0.1 | 0.1 | 96.4 |

* Also includes those who reported "no," which number could not be separated in the tabulation.
† Less than 1/10 of 1 per cent.

protection for the employer. It is evident, however, that even for these fields such a contract is seldom required. This freedom from restriction with regard to other employment is also apparent from table VI. Only 2 functional classes—teaching and sales—covered more than 1.0 per cent of their respective totals, and in neither did the period of contract exceed one year. In the teaching profession 2.5 per cent of the engineers were under separation contract and in sales 1.9 per cent; none of the other groups exceeded 0.8 per cent. Notwithstanding, it is significant that some 0.7 per cent of the engineers engaged in design and research were under separation contract for periods for 2 years and more.

#### Provision for Retirement on Pension

An analysis of the data furnished by professional engineers concerning their pension privileges is presented in table VII. As of December 1934, 10,641, or almost 1/3, of the 35,559 professional engineers reporting who had engineering jobs at that time stated that they had pension privileges. Of this number, 6,684, or 18.8 per cent, were covered by contributory pension schemes, and 3,957, or 11.1 per cent by noncontributory schemes. Some 57.8 per cent were in employments for which no pension provision had been made. About 12.3 per cent did not furnish information.

Of the engineers in pensionable positions, the smallest relative proportion, 26.2 per cent, were engaged in private engineering. By contrast, 37.4 per cent of the engineers engaged in public engineering and 29.0 per cent of those in personal service had pension privileges. It may be noted also that for public engineering and personal service the contributory scheme predominated. Of the engineers engaged in private engineering, the largest proportion was covered by noncontributory systems. However, within the private-engineering group marked differences were shown; the same was true of the 3 categories of public engineering.

The largest number of professional engineers covered by a pension plan were those in the employ of the Federal Government. Out of a total employment of 4,649 engineers reporting, 43.2 per cent were under a contributory and only 5.3 per cent under a noncontributory plan. The corresponding proportions in positions with state and

### Table VI. Distribution of All Engineers Reporting Separation Contract, by Type of Work Engaged in at End of 1934

| Type of Work | Number: Total | Number: Under Contract for—Under 1 Year | Number: Under Contract for—1 and Under 2 Years | Number: Under Contract for—2 Years and Over | Number: Under Contract, No Period Reported | Number: Not Reporting* | Per Cent: Total | Per Cent: Under Contract for—Under 1 Year | Per Cent: Under Contract for—1 and Under 2 Years | Per Cent: Under Contract for—2 Years and Over | Per Cent: Under Contract, No Period Reported | Per Cent: Not Reporting* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All types | 34,101 | 274 | 72 | 122 | 93 | 33,540 | 100.0 | 0.8 | 0.2 | 0.4 | 0.3 | 98.3 |
| Design and research | 9,050 | 68 | 33 | 62 | 15 | 8,872 | 100.0 | 0.8 | 0.4 | 0.7 | 0.2 | 97.9 |
| Construction | 8,233 | 45 | 9 | 2 | 18 | 8,159 | 100.0 | 0.5 | 0.1 | (†) | 0.2 | 99.2 |
| Operation | 8,276 | 52 | 12 | 33 | 16 | 8,163 | 100.0 | 0.6 | 0.1 | 0.4 | 0.2 | 98.7 |
| Consulting | 2,146 | 10 | | 9 | 8 | 2,119 | 100.0 | 0.5 | | 0.4 | 0.4 | 98.7 |
| Teaching | 2,050 | 51 | 6 | | 31 | 1,962 | 100.0 | 2.5 | 0.3 | | 1.5 | 95.7 |
| Sales | 1,513 | 28 | 6 | 5 | 1 | 1,473 | 100.0 | 1.9 | 0.4 | 0.3 | 0.1 | 97.3 |
| General administration and management | 2,833 | 20 | 6 | 11 | 4 | 2,792 | 100.0 | 0.7 | 0.2 | 0.4 | 0.1 | 98.6 |

* Also includes those who reported "no," which number could not be separated in the tabulation.
† Less than 1/10 of 1 per cent.

county, and municipal governments were very much less—26.9 and 1.3 per cent, respectively. For municipal-government employment the figures were 29.9 and 2.4 per cent. This order of difference parallels that of the proportions of engineers under civil service in these 3 classes of employment, but only in the case of the Federal Government are the 2 proportions closely related. This arises from the fact that, whereas all persons under Federal civil service must contribute to the retirement fund, this is not true to the same extent for employments under state and county, and municipal governments, where age, length of service, and salary are also taken into consideration.

**Table VII. Distribution of All Engineers Reporting Pension Privileges, by Field of Employment at End of 1934**

| | Number | | | | | Per Cent | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pension Privilege | | | | | Pension Privilege | | |
| Field of Employment | Total | No Pension | Contributory Plan | Non-contributory Plan | Not Reporting | Total | No Pension | Contributory Plan | Non-contributory Plan | Not Reporting |
| All employments | 35,559 | 20,556 | 6,684 | 3,957 | 4,362 | 100.0 | 57.8 | 18.8 | 11.1 | 12.3 |
| Private engineering | 21,604 | 13,207 | 2,265 | 3,387 | 2,745 | 100.0 | 61.1 | 10.5 | 15.7 | 12.7 |
| Construction | 3,437 | 2,445 | 174 | 138 | 680 | 100.0 | 71.1 | 5.1 | 4.0 | 19.8 |
| Extractive industries | 1,841 | 1,109 | 272 | 200 | 260 | 100.0 | 60.2 | 14.8 | 10.9 | 14.1 |
| Public utilities | 4,183 | 1,833 | 341 | 1,555 | 454 | 100.0 | 43.7 | 8.2 | 37.2 | 10.9 |
| Transportation | 1,255 | 576 | 120 | 416 | 143 | 100.0 | 45.9 | 9.6 | 33.1 | 11.4 |
| Manufacturing | 10,888 | 7,244 | 1,358 | 1,078 | 1,208 | 100.0 | 66.5 | 12.5 | 9.9 | 11.1 |
| Public engineering | 11,177 | 5,791 | 3,827 | 357 | 1,202 | 100.0 | 51.8 | 34.2 | 3.2 | 10.8 |
| Federal Government | 4,649 | 1,850 | 2,009 | 248 | 542 | 100.0 | 39.8 | 43.2 | 5.3 | 11.7 |
| State and county governments | 4,438 | 2,723 | 1,193 | 58 | 464 | 100.0 | 61.3 | 26.9 | 1.3 | 10.5 |
| Municipal governments | 2,090 | 1,218 | 625 | 51 | 196 | 100.0 | 58.3 | 29.9 | 2.4 | 9.4 |
| Personal service | 2,778 | 1,558 | 592 | 213 | 415 | 100.0 | 56.1 | 21.3 | 7.7 | 14.9 |

Among the remaining fields of activity, public utilities and transportation reported the next highest proportions (after Federal employment) as having pension privileges. Public utilities and transportation used the noncontributory scheme; this type of plan covered 37.2 per cent in utilities and 33.1 per cent in transportation; contributory systems covered only 8.2 and 9.6 per cent, respectively, of those reporting. For the 3 remaining pursuits shown under private engineering, the largest number of engineers with pension privileges did not exceed 25.7 per cent, and in all cases contributory schemes predominated.

From the preceding discussion of the pension privileges it is quite evident that the kind of employment has a marked effect upon the question of the installation of a pension scheme. In no type of engineering employment was a majority of the reporting engineers protected by such a plan.

## Patent Privileges in the Engineering Profession

Information as to patent privileges was furnished by 61.6 per cent of the 35,559 reporting engineers with engineering jobs at the end of 1934 (table VIII). Of all engineers covered, 31.7 per cent reported retention of the patent rights for all inventions made either in the course of their work or in fields not directly related to their work. Among the nine separate fields of employment this was true of the largest group in each case, except in manufacturing where the highest proportion (30.1 per cent) reported that they had no rights to patents relating to their work, but did retain their rights to those not directly related to their work. This latter combination ["(1) no; (2) yes," in table VIII] ranked second in importance and included 16.9 per cent of the 35,559 engineers. The third group in importance (including 4,575, or 12.9 per cent) was that reporting complete restriction on both aspects of patent privileges. Only 42 engineers, less than 0.1 per cent of the total, reported that they retained the rights to inventions connected with their duties but not to those not so connected.

It would seem that, comparatively, there is only slight restriction on the retention of patent rights among professional engineers, although its extent varies in the different fields of employment. Thus, relatively the greatest restriction was placed upon engineers engaged in manufacturing 19.0 per cent of whom reported complete restriction, 30.1 per cent the right to patent inventions not directly related to their work but not to those made in the course of their work, and only 23.1 per cent no restrictions. In the extractive industries the limitations, while less severe than in manufacturing, were nevertheless greater than in any of the other branches of private engineering. Complete restriction was reported by 15.6 per cent of the engineers in the extractive industries, by 11.8 per cent of those in construction, and by 11.4 per cent of those in transportation; the smallest proportion, 8.9 per cent, was reported for engineers in the employ of public utilities.

It has already been noted that in manufacturing, some 30.1 per cent of the engineers so engaged had the right to patent inventions not directly related to their work, but not to those made in the course of their work. This partial restriction was very much less for the remaining fields of activity in private engineering. In extractive industries, only 18.6 per cent so reported, in transportation 17.3 per cent, and in public utilities 16.0 per cent. Partial restriction affected only 8.6 per cent of the engineers engaged in construction. These same 4 fields of activity,

however, did report larger proportions as being unrestricted with regard to patent privileges. These ranged from 32.6 for extractive industries to 42.4 per cent for public utilities. In this regard, it may be recalled that only 23.1 per cent of the engineers in manufacturing so reported.

In the 3 classes of public engineering, there was a marked divergence in the restrictions placed upon patent privileges. This was greatest for engineers in the employ of the Federal Government, 12.2 per cent of whom had no patent privileges whatsoever, whereas in state and country, and municipal governments only some 9.0 per cent were under complete restriction. Partial restriction affected 12.5 per cent of the Federal Government engineers, but only about 5.5 per cent of those in the other 2 public employments. The greatest divergence occurred for those engineers who reported they had the right to patents made in the course of their work and also to those not directly related to their work. This group included only 21.7 per cent of Federal Government engineers, whereas

### Table VIII. Distribution of All Engineers Reporting Patent Rights, by Field of Employment

| Field of Employment | Total | Right Retained to Inventions (1) Made in the Course of Work, and (2) Not Directly Related to the Work: (1) Yes; (2) Yes | (1) Yes; (2) No | (1) No; (2) Yes | (1) No; (2) No | Not Reporting |
|---|---|---|---|---|---|---|
| **Number** | | | | | | |
| All employments | 35,559 | 11,263 | 42 | 6,017 | 4,575 | 13,662 |
| Private engineering | 21,604 | 6,499 | 29 | 4,801 | 3,279 | 6.996 |
| Construction | 3,437 | 1,178 | 5 | 294 | 405 | 1,555 |
| Extractive industries | 1,841 | 601 | 2 | 342 | 288 | 608 |
| Public utilities | 4,183 | 1,771 | 6 | 670 | 374 | 1,362 |
| Transportation | 1,255 | 434 | 3 | 217 | 143 | 458 |
| Manufacturing | 10,888 | 2,515 | 13 | 3,278 | 2,069 | 3,013 |
| Public engineering | 11,177 | 3,364 | 10 | 946 | 1,150 | 5,707 |
| Federal Government | 4,649 | 1,009 | 3 | 582 | 567 | 2,488 |
| State and county governments | 4,438 | 1,587 | 5 | 249 | 386 | 2,211 |
| Municipal governments | 2,090 | 768 | 2 | 115 | 197 | 1,008 |
| Personal service | 2,778 | 1,400 | 3 | 270 | 146 | 959 |
| **Per Cent** | | | | | | |
| Total, United States | 100.0 | 31.7 | 0.1 | 16.9 | 12.9 | 38.4 |
| Private engineering | 100.0 | 30.1 | 0.1 | 22.2 | 15.2 | 32.4 |
| Construction | 100.0 | 34.3 | 0.1 | 8.6 | 11.8 | 45.2 |
| Extractive industries | 100.0 | 32.6 | 0.1 | 18.6 | 15.6 | 33.1 |
| Public utilities | 100.0 | 42.4 | 0.1 | 16.0 | 8.9 | 32.6 |
| Transportation | 100.0 | 34.6 | 0.2 | 17.3 | 11.4 | 36.5 |
| Manufacturing | 100.0 | 23.1 | 0.1 | 30.1 | 19.0 | 27.7 |
| Public engineering | 100.0 | 30.1 | 0.1 | 8.5 | 10.3 | 51.0 |
| Federal Governments | 100.0 | 21.7 | 0.1 | 12.5 | 12.2 | 53.5 |
| State and county governments | 100.0 | 35.8 | 0.1 | 5.6 | 8.7 | 49.8 |
| Municipal governments | 100.0 | 36.7 | 0.1 | 5.5 | 9.4 | 48.3 |
| Personal service | 100.0 | 50.4 | 0.1 | 9.7 | 5.3 | 34.5 |

for state and county, and municipal governments the percentages reported were, respectively, 35.8 and 36.7.

Relative to all other fields of activity, the least restrictions were found in personal service, where 50.4 per cent reported unrestricted patent rights, 9.7 per cent partial restriction, and only 5.3 per cent no patent privileges. This freedom from restriction in the retention of patent rights for engineers in the personal-service group was due to the preponderance of teachers in this group, as examination of table IX shows.

Engineers engaged in teaching were under the least restriction as to the retention of patent rights, and

### Table IX. Distribution of All Engineers Reporting Patent Rights, by Type of Work Engaged in at End of 1934

| Type of Work | Total | Right Retained to Inventions (1) Made in the Course of Work, and (2) Not Directly Related to the Work: (1) Yes; (2) Yes | (1) Yes; (2) No | (1) No; (2) Yes | (1) No; (2) No | Not Reporting |
|---|---|---|---|---|---|---|
| **Number** | | | | | | |
| All types | 34,101 | 10,828 | 40 | 5,779 | 4,401 | 13,053 |
| Design and research | 9,050 | 2,128 | 13 | 2,404 | 1,430 | 3,075 |
| Construction | 8,233 | 2,730 | 8 | 717 | 892 | 3,886 |
| Operation | 8,276 | 2,737 | 10 | 1,494 | 1,108 | 2,927 |
| Consulting | 2,146 | 695 | 3 | 202 | 246 | 1,000 |
| Teaching | 2,050 | 1,132 | 3 | 199 | 90 | 626 |
| Sales | 1,513 | 453 | 2 | 310 | 293 | 455 |
| General administration and management | 2,833 | 953 | 1 | 453 | 342 | 1,084 |
| **Per Cent** | | | | | | |
| All types | 100.0 | 31.8 | 0.1 | 16.9 | 12.9 | 38.3 |
| Design and research | 100.0 | 23.5 | 0.1 | 26.6 | 15.8 | 34.0 |
| Construction | 100.0 | 33.2 | 0.1 | 8.7 | 10.8 | 47.2 |
| Operation | 100.0 | 33.1 | 0.1 | 18.1 | 13.4 | 35.3 |
| Consulting | 100.0 | 32.4 | 0.1 | 9.4 | 11.5 | 46.6 |
| Teaching | 100.0 | 55.3 | 0.1 | 9.7 | 4.4 | 30.5 |
| Sales | 100.0 | 29.9 | 0.1 | 20.5 | 19.4 | 30.1 |
| General administration and management | 100.0 | 33.6 | † | 16.0 | 12.1 | 38.3 |

† Less than 1/10 of 1 per cent.

engineers in design and research were under the greatest restriction. Of the 9,050 engineers classified as working in design and research, only 23.5 per cent had the right both to patents made in the course of their work and those not directly related to their work. As many as 55.3 per cent of the engineers engaged in the teaching of engineering subjects so reported. For the remaining 5 lines of work, the proportions with full rights to patents ranged from 29.9 per cent in sales to 33.6 per cent in general administration and management.

Relatively, the largest proportion of engineers who were partially restricted in regard to patent rights (26.6 per cent) was reported for design and research. Even in the case of sales, some 20.5 per cent were classified under this "no–yes" combination. By contrast, only 18.1 per cent of the engineers engaged in operation and 16.0 per cent in general administration and management were restricted only as to patents relating to their work. The corresponding proportions in construction, consulting, and teaching were very much less, ranging from 8.7 in construction to 9.7 in teaching.

The largest relative percentage completely restricted was 19.4—for the engineers engaged in sales—with design and research following next in order (15.8 per cent). From this point the proportion ranged downward to 13.4 per cent in operation, 12.1 per cent in general administration and management, 11.5 per cent in consulting, and 10.8 per cent in construction. The lowest percentage under complete restriction, namely 4.4, was noted in teaching.

# The Ultrahigh-Frequency Domain

By ALFRED N. GOLDSMITH
FELLOW AIEE

**Use of ultrahigh frequencies for educational broadcasting has been thought to offer attractive possibilities because of the supposedly almost unlimited number of channels; however, the demands of other radio services, particularly television, may be expected to congest this newly opened region. Ultrahigh-frequency waves behave somewhat like light waves, and give reliable and steady communication over short distances. The 6-megacycle band width required for television can be accommodated only in this region, but short range precludes, for the present, coverage of rural areas with these frequencies.**

THE ultrahigh-frequency waves have attracted considerable attention of late. It is but natural that educators have frequently considered the possible application of these waves for local educational broadcasting. In some quarters the optimistic thought has been expressed that in this new domain there will be space for the establishment of almost any number of local educational broadcasting stations. It will be attempted later in this presentation to analyze the probability of the successful execution of such a plan.

## Frequency Regions for Broadcasting

The radio waves referred to as lying in the "ultrahigh-frequency domain" are, broadly speaking, those having a wave length less than 10 meters. They result from electrical oscillations having frequencies greater than the extremely high value of 30,000,000 cycles or oscillations in each second. The waves in the existing broadcasting band—that is, the so-called "medium waves"—have lengths lying between about 200 and 550 meters, and correspond to electric oscillations of a frequency in the general neighborhood of 1,000,000 cycles per second. Lying between the medium waves for broadcasting and the ultrahigh-frequency domain are the short waves which are so effectively used, among other purposes, for transoceanic and transcontinental communication.

There is one additional region used for broadcasting, namely, that of the longer waves in the neighborhood of 1,500 meters, having a frequency of about 200,000 cycles per second. These waves are not used for broadcasting in America although they have had considerable application in Europe.

Thus there are, so to speak, 4 domains of possible interest for modern broadcasting. These are the long waves, having frequencies of the order of 200,000 cycles per second; the medium waves (so widely used in the United States), having frequencies of the general order of 1,000,000 cycles per second; the short waves, having frequencies of the order of 10,000,000 cycles per second; and, finally, the ultrashort waves, which have the ultrahigh frequencies of from 30,000,000 to several hundred million cycles per second or even more.

It was hinted that the short waves were not widely useful for national broadcasting. They do serve admirably to cover the great distances required to span oceans, but they give a relatively poor local service and create so considerable an amount of interference at distant points in other countries when they are used for primarily local broadcasting that it seems inappropriate to regard them as a proper means for completely carrying out national broadcasting in such countries as the United States.

Accordingly, so far as future expansion of the broadcasting realm is concerned, attention must be concentrated on the ultrahigh-frequency domain. The nature of these waves is worth considering more fully. To begin with, they are a good deal more like visible light than are the short, medium, or long radio waves hitherto used. By this is meant that these waves are more readily blocked by obstacles which would stop light; are reflected by objects somewhat like those which would reflect light; and have somewhat of the reliability and steadiness of transmission which light waves attain in the absence of fog or material obstacles.

## Ultrahigh-Frequency Transmission

Broadly considered, an ultrahigh-frequency transmitting station acts like a sort of radio lighthouse. Its rays travel outward in all directions toward the horizon and are best received along the "line of sight." For this reason it is common and approved practice to place the ultrahigh-frequency transmitting stations on the top of the tallest structure which may be available and also to place them, as nearly as practicable, in the center of the region which they are intended to serve. The higher the location of the transmitting station, the greater the range of satisfactory transmission.

It is true that the ultrahigh-frequency waves do not stop completely at the horizon but can be received, though with diminished strength and increased unsteadiness, at distances considerably beyond the optical horizon. It is also true that occasionally these waves may "fade" beyond their normal range, that is, fluctuate rapidly in their strength at the receiving station.

---

Essentially full text of an address presented at the First National Conference on Educational Broadcasting, Washington, D. C., December 10–12, 1936.

ALFRED N. GOLDSMITH is a consulting industrial engineer in New York, N. Y., and a Life Member of the AIEE. He received the degree of bachelor of science from the College of the City of New York, on the faculty of which he served for many years, the degree of doctor of philosophy from Columbia University, and, in 1935, the honorary degree of doctor of science from Lawrence College. Doctor Goldsmith is a past-president of the Institute of Radio Engineers and of the Society of Motion Picture Engineers, and is the author of many technical articles and books.

It has been reported that the occasional range of transmission and reception of the ultrahigh-frequency waves may be very considerable. Distances from 100 to several thousand miles have been cited in this connection. How frequently such extreme ranges may occur and upon what physical factors they depend are not yet known with certainty. Accordingly, a proper precaution is to suspend judgment as to the extent to which these facts will influence the allocation of the ultrahigh frequencies.

Nevertheless, taken by and large, the ultrahigh-frequency waves work best to distances little beyond the visible horizon, produce a steady and reliable signal with a minimum of distortion of the material transmitted (whether televisual or telephonic), and are relatively free from erratic changes in transmission. It is fair to state that, as a rule, the ultrahigh-frequency waves are transmitted with somewhat of the steadiness and constancy to be attained in a properly designed wire or cable system operating under the most favorable conditions.

Another fortunate aspect of the ultrahigh-frequency waves is the relatively low level of natural interference. It is well known that atmospheric electrical disturbances trouble radio listeners on the medium waves during the summer months, even in the northern portions of the United States. The ultrahigh-frequency waves, on the contrary, are little troubled from this source, though a number of man-made devices (such as the ignition systems of some automobiles and medical diathermal equipment) may cause serious interference with the reception of these waves at points near the outer limits of their service range. Fortunately automobile ignition systems can be shielded, and there is little doubt, should ultrahigh-frequency waves become widely used for broadcasting to the public, that the automobile industry will likely co-operate by taking such measures as will reduce ignition interference. Possibly diathermal outfits will be given their own assigned frequency, thus preventing most of the interference caused by them.

While the ultrahigh-frequency waves give reliable and steady communication, their service range, as indicated, is usually limited to distances of the order of several tens of miles from the transmitter. The questions will naturally be asked: Why should these waves be used in broadcasting? With their limited range what compensating advantages do they display? What can be accomplished by their use which cannot be otherwise accomplished? What broadcasting opportunities are thus offered? And what broadcasting methods, of special interest to educators, can thus be realized?

## Widths of Frequency Bands for Communication

Before answering these questions it is necessary to consider briefly the demands made upon radio transmission capabilities by the various forms of communication. The simplest form of communication is telegraphy—by dots and dashes. This requires a limited band of frequencies or "space in the air." Actually a few tens, or at most hundreds, of cycles per second are required next to one or both sides of the so-called carrier wave by telegraphic communication. Telephonic communication—the transmission of speech or music—makes more severe demands. In this case the frequency band required (that is, the so-called "side band") is about 10,000 cycles wide. The demands of facsimile communication—the transmission of drawings, printed text, writing, or photographs in the form of a record—requires perhaps a half or a third as much space for the corresponding frequency band as telephony. Then there is television, which is the most difficult of the communication arts. This is the transmission of pictures in motion, in transient form (that is, not recorded). The side band in this case rises in width to millions of cycles. For example, a side band about 2,500,000 cycles wide is believed to be required for really acceptable television pictures.

The difficulty of each of these methods of communication is somewhat proportionate to the side-band width required as previously indicated. This must not be taken too literally. However, it is fair to say that television is much more difficult than either telephony or facsimile which, in turn, exceed telegraphic communication in their technical requirements.

As hinted in the foregoing discussion, every transmission of intelligence by radio is accomplished by using a carrier wave for transmission and by modulating or controlling this carrier wave in such fashion as to convey the intelligence in question. The result of this modulation, in the simplest case, is to add new side bands on each side of a carrier wave; these side bands occupy frequencies to the exclusion of the interference-free reception of other communications of comparable strength on the same frequencies in the same general locality. (For the moment, the capabilities and advantages of directional reception are not under consideration.)

That television cannot be carried out, with adequate picture quality, on the medium broadcast waves becomes at once evident. Finding space on such waves, having an average frequency of a million cycles, for side bands several million cycles wide such as are required by television is not possible. It becomes necessary to go to the ultrahigh frequencies. If the carrier frequency has the ultrahigh value of say 50 megacycles there is obviously room on each side of this frequency for the side bands required by television, wide though such side bands be.

## Beam Transmission of Ultrahigh Frequencies

It is also desirable, before answering the questions which have been posed, to consider one other useful characteristic of the ultrahigh-frequency waves. These waves are quite short and are accordingly readily focused, if desired, so that they may be transmitted primarily in a given direction in a narrow beam. This is important whenever directional transmission and reception are required. A proposal has been made to use the ultrahigh-frequency waves for relay communications. In this process the transmission from a given station of these waves is picked up at a distant point by a corresponding receiving station, and the received signals are amplified powerfully by one means or another and then sent into a nearby second

transmitter which carries them along on their way to a further receiving station where the process of automatic relaying is carried out. Several such ultrahigh-frequency relay stations, each picking up its signal from the preceding and sending it forward along the relay system, would constitute a sort of network.

The difficulty experienced in using medium or long waves for the purpose of radio relaying involves the problem of efficient transmission and accurate reception. In this respect the ultrahigh-frequency waves are nearly ideal. They can be readily concentrated in a given direction toward the next relay station; and the amount of interference experienced in reception because of natural electrical disturbances is, as has previously been stated, relatively very slight and unimportant. For these reasons the ultrahigh-frequency waves lend themselves well to radio relay systems.

## Use of Ultrahigh Frequencies for Broadcasting

To some extent the questions which have been previously set forth can now be answered. First, as to the question: Why should the ultrahigh-frequency waves be used in broadcasting? The answer is that they show reduced distortion of quality, diminished interference from natural electrical disturbances, and a high degree of reliability of service within their normal range, which range is quite adequate to cover most urban and suburban areas or areas of corresponding size in rural regions. They require only reasonable amounts of power to accomplish such results provided the transmitting station is centrally located on the top of a high structure. Under usual conditions these waves do not cause severe distant interference and have only a limited "nuisance range," in contradistinction to the short and medium waves which sometimes cause interference at distances far beyond their range of useful reception. Further, the fact that the utilization of these waves might, if judiciously carried out and with due control, somewhat relieve the worst congestion now existing on the medium broadcasting waves cannot be overlooked. In the foregoing statement it is believed that there has similarly been answered the question: With their limited range what compensating advantages do they display?

The next question is: What can be accomplished by their use which cannot otherwise be accomplished? Through the use of ultrahigh-frequency waves it is possible to have more local stations which would be substantially noninterfering than would be the case if the medium waves were used. It is possible to establish more nearly constant day and night quality of service than is now the case. It is also feasible to maintain winter and summer reception on more nearly the same level of freedom from natural electrical disturbances. While it is true that man-made devices, such as automobile ignition systems and medical diathermal equipment, can interfere with ultrahigh-frequency reception, yet the reduction of such types of interference by organized planning, regulation, and industrial co-ordination offers greater possibilities than the elimination of natural disturbances—which latter have proved extremely stubborn as to their elimination by any methods of conventional sort requiring no increased width of frequency band for the corresponding transmission and reception. By the use of the ultrahigh-frequency waves it becomes at once possible to transmit telephone programs (that is, speech and music) on an extremely high-fidelity basis and, similarly, to receive these programs with such accuracy of reproduction in the home as will greatly enhance the clarity of speech and the naturalness of reproduction of music. Present-day broadcasting on the medium waves is greatly handicapped in its struggle to obtain high-fidelity transmission and reception by the congestion of stations on neighboring channels only 10,000 cycles (10 kilocycles) apart. Actually 3 times this separation could be used to advantage were it available—which it emphatically is not in a country like the United States where great areas must be covered, where numerous broadcasters insist on the privilege of transmission, and where occasionally political considerations may be urged in connection with the allocation of transmission frequencies. Broadly stated, more reliable local transmission, less interference from natural disturbances, a partial relief from certain types of congestion of transmission facilities, high-fidelity telephonic operation, and a steady and reasonably uniform all-day and all-year service can be anticipated from the ultrahigh frequencies.

## Use of Ultrahigh Frequencies for Television

Perhaps the greatest opportunity offered by the ultrahigh-frequency waves, namely, the introduction of television, has not as yet been analyzed. Here is one service, at least, which could not conceivably be carried out according to present knowledge on any but the ultrahigh-frequencies. Its side-band demands for an extraordinarily wide band of frequencies can be met only in this new domain. Since the visual services can reasonably be expected to add a great deal to the value of broadcasting as an educational medium in the broadest sense, there is no question but that the ultrahigh frequencies will find a wide and successful application for that purpose.

Only very recently was reasonably good agreement reached among experts as to what constitutes an acceptable type of television. In a broad way the television picture is described as having "a certain number of lines," the lines being the parallel and adjacent paths over which moves the spot of light that creates the television picture. Initially as few as 24 lines were suggested for an acceptable television picture. Actually such a picture would be of the utmost crudity and capable of giving an extremely rough impression of only the simplest objects. As time went on, 45-line pictures and then 60-line pictures were proposed. In each case the almost pitiful inadequacy of such television pictures, so far as any educational or entertainment value was concerned, became fully evident. There then followed attempts to use 120 and 180 lines of television pictures and, for the first time, a slightly useful television picture was produced. However, present-day experimental practice here and abroad involves pictures having 343 lines or 405 lines, respectively (although some

attempts are still made to use 240-line pictures). The proposed standard for the United States is a 441-line picture. At its best such a picture may be described, crudely enough, as definitely better than a projected motion picture from 8-millimeter film and perhaps nearly or quite as good as a motion picture projected from 16-millimeter film. The television standards so far proposed as practicable cannot be expected to give results equal to those obtained in an auditorium, for example, by the projection of 35-millimeter film. The pictures are monochrome—that is, essentially in black and white. Practical color television is a rather remote possibility and hardly one with which to be concerned for some time to come.

If television pictures having numbers of lines of between 300 and 500 are taken as a reasonable standard for the present, the side bands required for the corresponding transmissions are found to be extraordinarily wide as compared to those used for telephony. The proposed width for the side bands in the American television transmissions will be about 2,500,000 cycles per second. Only in the ultrahigh-frequency domain of waves can be found a practicable resting place for such transmissions. Accordingly television must necessarily embrace the capabilities and accept the limitations which have been previously described as associated with ultrahigh-frequency transmission and reception.

The establishment of a television transmitting station on the highest location in the region which is to be served is, nevertheless, unlikely to enable coverage over a range of more than a few tens of miles in each direction. While this is entirely adequate for most cities and their suburbs, it is certainly not adequate for the coverage of large rural areas where the concentration of lookers will be small and the distances to be covered will be great.

It may be judged from this that methods should be found, if possible, to give to television services an adequate rural coverage although it must be admitted that, up to the present, the problem of so doing is formidable both technically and economically. One may also conclude that the medium-frequency telephone broadcasting stations of today, while unable to render television service because of the limitations of medium-frequency transmission as pointed out previously, will nevertheless necessarily remain the backbone, so to speak, of the broadcasting structure in so vast a country as the United States, at least for many years to come. From this the comforting thought may be extracted that the present broadcasters do not face an abrupt obsolescence of their stations which, so far as can now be told, will still render a useful rural service in the future. No present means of replacing the rural service in question by technically correct and economically feasible utilization of ultrahigh-frequency transmissions is known. However, even these problems may in time be solved to the advantage of ultrahigh-frequency methods.

## Facsimile Broadcasting

Facsimile broadcasting is perhaps of particular interest to the educator since it is the only form of broadcasting which offers a permanent record of textual and graphic material. It is a sort of radio printing press located in the home and capable of producing pages (and even books, if given reasonable time). Facsimile broadcasting could technically be carried out on the existing broadcast frequencies, that is, the medium frequencies. The side bands required are little different from those necessary for telephony. However, the congestion in the present broadcasting band is so extreme that it would be out of the question at this time to add other services in the present broadcasting band. The interesting suggestion has been made that facsimile broadcasting might be carried out during the early morning hours on the existing broadcasting band, the reproduced material on sheets of paper being available to the recipient as he awakens in the morning. Such a service has distinct limitations and would likely be useful, if at all, only during an interim stage of development and as a facsimile service to rural areas not readily reached by ultrahigh-frequency transmissions.

If more or less continuous facsimile broadcasting is to be established in urban and suburban areas, it is more logical to expect that it will be associated with its related visual service—television. That is, facsimile broadcasting also finds a natural location in the ultrahigh-frequency domain. It must be left to the imagination of the educator to envisage the numerous attractive possibilities of instruction and examination which are afforded by this type of broadcasting. However, the limitations of range of the ultrahigh-frequency waves must be kept in mind here, as well as in the case of television broadcasting.

## Availability of Channels in the Ultrahigh-Frequency Domain

The likelihood of the successful establishment of a substantially unlimited number of ultrahigh-frequency educational stations for local broadcasting in a given neighborhood can now be analyzed. The television experts have reached the conclusion that the television-telephone channels must, for effective picture and sound transmission, be about 6,000,000 cycles (6 megacycles) wide. In studying television standards the committee on television of the Radio Manufacturers Association has proposed the use of the frequencies between 42 and 90 megacycles for television transmission (excluding the amateur band between 56 and 60 megacycles). In view of the impression which may exist that an indefinitely large number of television transmissions can be placed within this region it is interesting to know that there are only 7 available channels, each 6 megacycles wide, in this whole requested band of frequencies! Where 2 cities, like New York and Philadelphia, are about 100 miles apart, it is possible that television allocations would be so restricted as to provide say 4 television transmissions for New York City and 3 for Philadelphia. Otherwise stated—and this is a rather startling and discouraging fact—there appears to be space at this time in the ultrahigh-frequency domain for fewer television-telephone transmissions in a given locality than there is space for the usual telephone broadcasting channels in the existing medium-frequency band. Accordingly,

until even higher frequencies than 100 megacycles are available for satisfactory broadcasting of telephone, television, or facsimile material, it is unlikely that the average city can enjoy the privilege of simultaneous operation of more than a limited number of television-telephone transmissions. It has been the unhappy experience in radio broadcasting that the opening of a new domain always appeared to offer an almost limitless opportunity for simultaneous and noninterfering transmissions but, after practical examination and test, it has turned out to offer extremely few opportunities in comparison with the number anticipated. In fact, no radio domain so far rendered available has, after a reasonable time of development, been free from marked congestion at some time. Unfortunately there is no present reason for believing that the ultrahigh-frequency domain will be an exception to this experience of the past, and whatever congestion now exists in broadcasting may be expected to continue when the ultrahigh-frequency waves are used.

It would probably be good counsel to the educators of the United States to advise them to keep fully informed on the technical and industrial developments in the ultra-high-frequency domain and to study carefully in advance what may probably be accomplished by the use of the radio and visual broadcasting services which can be established in this domain. It would also be well if carefully planned broadcasting of educational material were carried out, using these new frequencies and the novel forms of transmission, such as facsimile and television, which they render possible. However, if education is to derive its full benefit from these new instrumentalities of science, it will involve much sober thought, co-operative effort, and systematic planning on the part of educators. The field is too complex and its problems too numerous to make an unplanned success at all probable or to reward casual, meager, or purely selfish efforts.

Beyond a doubt, engineers will do their utmost to perfect the approaching art of television and facsimile broadcasting and of telephone broadcasting as well, all on the ultrahigh frequencies. It is hoped that the educators of America, fully awakened to the interesting civic possibilities which these communication media offer, will similarly avail themselves of their potentialities systematically and effectively.

### Practical Limitations of

# The Broadcast Allocation Structure

By C. B. JOLLIFFE
MEMBER AIEE

**To give the radiobroadcast listener maximum service is an important problem in which the frequencies available, characteristics of the receiving set, phenomena of transmission of radio waves, area to be served, and density of population in the area must be considered. Broadcast stations in the United States are of 2 main classes, clear channel and duplicated channel, and are allocated in frequency to prevent interference between stations in the same area. Short-wave broadcasting has additional limitations because of natural phenomena.**

BROADCASTING, as it is known today, is a newcomer in radio communication. Consequently, since its start in 1921 when a single frequency was made available for the service, radiobroadcasting has had to make its own place in the radio spectrum purely on the basis of public interest and public acceptance. It has been estimated that at the end of 1936 approximately 30,000,000 radio receiving sets were in use in the United States. This alone is ample proof that the public has accepted broadcasting. If nothing else were considered, the huge investment of the public in this industry is sufficient to give broadcasting a position of commanding importance. Because of its great importance to the public, a thorough understanding of the underlying principles of broadcast allocation is necessary in order to judge the effectiveness of any allocation or in order to make constructive suggestions concerning improvements.

In the frequency spectrum, broadcasting of the United States has been allocated the space from 550 to 1,600 kilocycles for domestic service and several frequency bands between 6,000 and 22,000 kilocycles (6,000–6,150; 9,500–9,600; 11,700–11,900; 15,100–15,350; 17,750–17,800; 21,450–21,550) for international service. This discussion will be limited to these bands of frequencies.

Essentially full text of an address presented at the First National Conference on Educational Broadcasting, Washington, D. C., December 10–12, 1936.

C. B. Jolliffe is engineer in charge of frequency bureau, Radio Corporation of America, New York, N. Y., and is chairman of the AIEE committee on communication. He received the degrees of bachelor of science and master of science from West Virginia University and the degree of doctor of philosophy from Cornell University. From 1922 to 1930 he was associate physicist in the Bureau of Standards, Washington, D. C., and from 1930 to 1935 was chief engineer of the Federal Radio Commission and its successor, the Federal Communications Commission. Doctor Jolliffe has served as delegate or technical adviser for several international radio conferences.

In the band from 550 to 1,600 kilocycles the principles of broadcast allocation have become fairly definitely stabilized. However, the average listener who tunes across the dial of his receiving set may well wonder if there is system and order behind what he hears. Why is he able to receive on some points of the dial while at other points he hears a mixture of signals from many stations? Why is not every point or every channel on the radio dial available to give him perfect service? What should a listener expect to hear on his receiving set? The answers to these questions are not immediately obvious, but the answers are relatively simple when one studies the bases of allocation used in the United States and the severe limitations imposed on the allocation of frequencies to broadcast stations. It is the purpose of this article to discuss these limitations of broadcast allocation and give a brief picture of the structure under which the broadcasting industry operates at the present time.

## Medium-Frequency Broadcasting Service

### Number of Frequency Channels Available

The fundamental limitation to every radio service is the frequency space available for that service. All the radio communication services of the world work in a common transmission medium referred to as the ether. Radio waves of all frequencies can exist in this medium and retain their separate identities, that is, there is no mutual interference between radio waves in space. There is projected into this medium all types of signals—point-to-point telegraph communications, telephone communications, communication between police cars and headquarters, military communications, communication between amateurs, ship to shore telegraph and telephone, and so forth. If a receiving set which had no frequency discrimination were used, all these communications would be heard simultaneously as a jumble. Fortunately, receiving sets can discriminate with respect to frequencies and it is possible to pick out one band of frequencies and reject all others.

Consequently, it is necessary first to arrange the various kinds of communications in different frequency bands in such a way that receiving sets can pick out the band desired. Different groups of frequencies are assigned for use by different services and receiving sets are used which are designed to accept frequencies of a particular service.

At international conferences in which all nations of the world participate, the common communication medium has been carved into frequency bands which have been allocated to various classes of services.* Broadcasting has been allocated frequency space which the nations of the world believe to be its proportionate share of these frequencies. In North America there has been allocated the band of frequencies from 550 to 1,500 kilocycles for the exclusive use of broadcasting for the purpose of providing domestic broadcast service as it is known today. Because no interference to other parts of the world will be caused, the nations of North America have further agreed to use the space from 1,500 to 1,600 kilocycles for broadcasting. Similarly, the nations of Europe have agreed among themselves to use other frequencies (below 400 kilocycles) for broadcasting which do not cause interference in North America. The agreements concerning use of frequencies have been made by the duly accredited representatives of all nations of the world, including the United States, and are a part of the fundamental law.

The United States, then, has one of the pieces of the frequency spectrum, 550–1,600 kilocycles, available for broadcasting. The size of this piece is not likely to be changed. The duty of the Federal Communications Commission, which is the agency of the government charged with the administration of the radio laws and the assignment of frequencies to stations, is to assign frequencies in this space to broadcast stations in such a manner as to provide the best broadcast service possible to the people of the United States.

The Commission has decided that stations will be allocated at intervals of 10 kilocycles through the space 550–1,500 kilocycles. This provides, then, using channels at both ends of a block of frequencies, 96 channels of communication for use in North America. Assuming that the frequency space from 1,500 to 1,600 kilocycles will be assigned eventually on the same basis, 10 more channels may be added, making a total of 106 for use by broadcast stations in this band. By agreement between the United States and Canada, 6 frequencies have been allocated for the exclusive use of the latter. Thus a total of 100 channels remains for use by stations of the United States. This then is the first limitation of broadcast allocation.

### Performance of Receiving Set

The radio receiving set used by the listener constitutes the second limitation on allocation. Broadcast stations are assigned at intervals of 10 kilocycles. In order to have satisfactory radio reception it is necessary that but one program be reproduced in the output of the receiving set. The antenna which is used to pick up a minute amount of power from the transmission medium has flowing in it currents of all frequencies produced by transmitting stations of corresponding frequencies. The function of the receiving set is to pick out, amplify, and reproduce the currents produced by the one transmitting station desired and reject all others.† If 2 transmitting stations separated by 10 kilocycles produce in the receiving antenna approximately equal currents, most receiving sets can receive one station and reject the other. If the 2 stations are separated by 20 kilocycles the unwanted station can be approximately 20 times the strength of the wanted station and the receiving set can select one from the other. If the ratio is greater than this then the average receiving set cannot make a clear distinction This ability of the receiving set to accept one station and reject another is referred to as the selectivity of the receiving set, and is the factor which makes possible the

* Article 7, General Radio Regulations annexed to the International Telecommunication Convention, Madrid, 1932, Treaty Series No. 867.

† "Characteristics of American Broadcast Receivers as Related to the Power and Frequency of Transmitters," Arthur Van Dyck and D. E. Foster. IRE *Proceedings*, volume 25, April 1937, page 387.

operation of many stations at the same time.

Some may remember in the early days of broadcasting that reception of one station without at the same time receiving signals from several other stations was extremely difficult. The development of the modern receiving set has been one of increasing its selectivity and approaching that ideal by which it is possible to accept one signal and reject all others regardless of their intensity.

Technical limitations make impossible the complete accomplishment of the ideal in the present state of the art. It is sufficient to state that with the present development it is possible to receive a signal on a given frequency and reject all others separated by 50 kilocycles or more regardless of their intensity. At less frequency separation than 50 kilocycles with modern receivers rejection of adjacent frequencies is possible provided they do not exceed certain values, the value which may be present decreasing as the frequency separation decreases.

A modern receiving set is a marvel of ingenuity which is accepted and used with little thought of the amount of work which has gone into its design and production. It is the best that engineers have been able to design and produce at a cost which can be borne by the listener. It does, however, represent the second limitation in allocation.

### Transmission of Radio Waves

The third limitation is the most fundamental and one which is imposed by nature; that is, the ability of radio waves once radiated to travel through space. When an alternating current of high frequency flows in an elevated conductor there is set up around it an electromagnetic field which moves through space with the speed of light. Variations in the intensity of the current flowing in the conductor produce similar variations in the electromagnetic field which make it possible for these electromagnetic waves to carry a message through space. Once these electromagnetic waves have left the antenna there is nothing which man has conceived to date that can be done to alter their course. The intensity of these waves at any given point is proportional to the amount of current flowing in the elevated conductor or antenna, and falls off rapidly as the distance between the antenna and the receiving point is increased.

At night a further complication is introduced. There is no simple transmission along the ground. The waves which leave the antenna at an angle from the ground and which in the daytime are usually lost in space, at night encounter what appears to be an electrical mirror at a height of some 50 to 100 miles above the surface of the earth. This electrical mirror returns the waves to earth and they are then capable of producing currents in the antenna of the receiving set even though the distance be very great.

This electrical mirror is not uniform and the waves which return are consequently not of uniform intensity. This gives rise to the phenomenon which has been called "fading." There are 2 types, one of which is produced when the reflected wave and the wave that is propagated along the ground both are of sufficient intensity to produce currents in the antenna. These waves having arrived over different distances and being of different phase interfere with each other and produce variations in the current produced in the receiving antenna. Irregularities in the reflecting medium vary the intensity and phase of the reflected wave while the intensity of the ground wave remains constant. This is the first type of fading which is encountered as one proceeds from the transmitting station. This fading is usually quite severe and one of its characteristics is that it is selective so that certain parts of the speech or music may cancel out entirely and other parts remain or are augmented. This results in severe distortion and very unsatisfactory reception. There is no known practical remedy for this type of fading and it is the limit of good service of many broadcast stations.

Beyond this region of interference between "ground" and "sky" wave the sky wave predominates and fading is due to irregularities in the reflection of the waves. This fading, the second of the 2 types, is usually not selective and all portions of the program change equally. This type of fading is substantially corrected by the modern receiving set by means of automatic control of the amount of amplification used by means of the intensity of the incoming signal.

The phenomenon of transmission of radio waves is extremely complex and in order to understand the laws governing it a large amount of experimental data must be obtained. These data have been accumulated over a period of years and it is believed that what to expect under any given set of circumstances is now known. The laws governing these transmissions are as exact and as certain to operate as the laws of gravitation. Man cannot alter them, he can only learn the fundamental bases and adapt himself to these bases. He may be able to apply apparatus and equipment which make better use of the transmitted signal, but he must always recognize that nature has set this limitation.

A corollary to this limitation of transmission is that of interference. When 2 radio waves of approximately the same frequency exist simultaneously in space they will produce in the antenna of the receiving set alternating currents of approximately the same frequency. The receiving set which depends on differences in frequency in order to select between 2 stations can make no selection when the frequencies it receives are the same. Consequently the signals carried by both radio waves will produce signals in the output of the receiving set. In order that one signal may be heard above the other it must be of sufficient strength that it can completely mask the other so that the receiving set appears to reproduce only one signal; in short, a shout drowns out a whisper.

Nature is also a broadcaster and produces radio waves which travel through space as do other radio waves. Every discharge of electricity in the form of a spark sets up electromagnetic waves. The noise produced by thunderstorms, which is usually referred to as static or atmospherics is familiar to all. The general accumulation of electrical discharges in space between clouds and between clouds and ground sets up a background of radio noise which

is picked up by the receiving antenna. Added to this there are the spark discharges produced in all types of electrical apparatus such as motors, generators, and flashing signs. This group of transmitters produces radio noise which is usually referred to as background noise. It is always present in a greater or lesser degree. In highly congested centers of population the background noise produced by electrical machinery may be extremely high while in a rural section with little electrification it may be practically zero. The natural noise produced by natural discharges is usually very high in the summer, particularly in the tropics, and practically nothing in the winter. The minimum amount of signal considered necessary to render good service under varying conditions is a measure of the amount of noise present on the average.

### Area and Distribution of Population

The final limitation of allocation is the size of the United States and the distribution of its population. The population of the United States is distributed over an area of approximately a rectangle 3,000 by 1,500 miles. The distribution of population varies from many thousands per square mile in highly concentrated centers of population to an average of less than one per square mile in wide open spaces. The time at which people are listening to broadcast programs varies, depending on time zones and habits of the various classes of people. It is not possible to change these factors, but it is possible to know what they are and act accordingly.

These are the technical limitations. None of them has been gone into exhaustively in this paper; any one of them is a subject for a paper itself. When broadcasting started there was little information available. As broadcasting has developed it has developed its instruments and measurements and accumulated its data. That which it is necessary to know concerning all of these limitations may be said now to be known. They can be analyzed and used in building and improving an allocation structure. They cannot be ignored simply because what they produce is not liked. Legislation and regulation may dictate or limit how these principles can be applied but they cannot change the fundamental technical laws.

### Plan of Allocation

How these limitations have been recognized and applied may now be briefly considered. That these applications are the only methods which might be used is not inferred, but they are used as illustrations of what has been done and what is familiar to everyone.

Stations of the United States have been classified into 2 different main classes: stations operating on clear channels, that is, one station only permitted to operate at night using the maximum amount of power; and stations operating on duplicated channels, that is, 2 stations or more permitted to operate simultaneously on each channel.

Stations of different classifications are distributed throughout the United States in such a manner that stations operating on adjacent frequencies are separated geographically from each other, thus recognizing the limitation in selectivity of the receiving sets. So when a listener is near one station, stations on channels 10, 20, 30, and 40 kilocycles removed therefrom are at distances from the listener so that the signals from them should always be below the values necessary to cause interference to the nearby station.

The Commission and station operators have recognized that the service area of a station is of 2 kinds, primary service and secondary service. The primary service is that area in which all listeners get service free of interference. The secondary area is that area in which the listeners get some amount of satisfactory service, but which is not always free of interference. For clear channel stations the primary area may extend for 100 to 150 miles up to the point of severe and selective fading. Beyond this area of severe and selective fading there exists a secondary area which extends to the limit of useful signal produced by the station. This useful limit of the secondary area is fixed by the amount of natural noise and consequently changes from day to day and season to season.

It should not be expected that everywhere within this secondary area there is freedom from interference and that the whole of the United States is within the secondary area of every clear channel. The limitation of radio-wave propagation limits the distance for which it will be useful. Also, the strength of signals from stations on adjacent frequencies will make the signal of no use in certain areas. If the secondary area of a clear channel station were charted it would consist of a map of the United States with many areas removed, the amount removed depending on the location of the stations on adjacent channels and the noise intensities in various areas.

Stations which operate on duplicated channels have their night service area limited by interference from the other stations operating on the same channel. At night these stations have very little, if any, secondary service and their primary service can be very accurately defined; in fact, so accurately defined that its use as a basis for estimating the number of people who can be served by the station is possible.

A station operating on a duplicated channel, therefore, is used to serve a center of population and is not expected to have any service at night beyond its normal service area limited by interference from other stations on the same channel.

The result of the allocation is, therefore, that clear channel stations serve centers of population with primary service up to the beginning of fading and then have a very extended secondary area, and stations operating on duplicated channels serve centers of population but have no secondary service, the entire service lying within an area relatively close to the station.

### Service Received by the Listener

From the listener's standpoint, then, if he lives in the good service area of either a clear-channel station or a station operating on a duplicated channel, he should obtain excellent service free of interference from these stations. In addition he should be able to receive the secondary service from many of the clear channel stations. This secondary service is usually less satisfactory than the pri-

mary service from a local station. However, program content may cause him to listen to a less satisfactory signal rather than his local signal free of interference.

Turning now to the questions which were asked in opening this paper, the answer is that the distribution of population over the United States, and consequently distribution of radio stations, makes it necessary that persons in some localities be deprived of service on certain channels in order that persons in other localities can have primary service. If, for example, the people of Washington, D. C., had perfect service on all 100 channels then the people in all cities beyond approximately 100 miles from Washington, D. C., would have to depend entirely on secondary service. This example can be carried to any center of population.

A person in a given locality should be able to hear all the stations which have their primary service area covering his locality, plus the secondary service from clear channels. Persons who do not live in a center of population having local service must depend entirely on the secondary service from clear channel stations. On duplicated channels on which no station gives primary service in his area he will simply hear a mixture of signals. These channels are giving primary service to other areas.

## High-Frequency Broadcast Service

The limitations and use of the frequencies used for international broadcasting, that is, frequencies between 6,000 and 22,000 kilocycles may now be discussed very briefly. These frequencies by their very nature are capable of world-wide interference and a type of world-wide service. In the frequency band above 6,000 kilocycles practically all of the radio commerce of the world is carried; communication between ship and shore, between the United States and all other countries of the world, and among the other countries of the world. This communication service puts a severe load on the frequency spectrum. Because of this large load of commercial traffic only a very small portion of the frequency spectrum has been allotted to broadcasting.

The transmission characteristics of these frequencies change very markedly as the frequency range is changed, as the transmission path changes from daylight to dark, and as the seasons change. These characteristics are well known.

A frequency of the order of 15,000 kilocycles for example, used for transmission from a station produces very little service in its immediate neighborhood, but does produce in the daytime a very strong signal at distances of greater than approximately 1,000 miles away. In other words, if an observer were to travel out from a station with a receiving set he would find that its service fell off very rapidly in the first few miles, then disappeared for several hundred miles, and then began to reappear again. This distance in which the signal vanishes is called the "skip" distances for that frequency. Skip distance varies from a few miles for the lower frequencies in the daytime to thousands of miles for the higher frequencies at night. In fact, frequencies above approximately 10,000 kilocycles are useless at night because their skip distance is greater than half way around the world. Because of this characteristic of transmission, in order to serve a particular point or a particular area at a distance from the station, it is necessary to use a different frequency in the daytime than at night and also a different frequency in winter than is used in summer. Consequently, to permit continuous service to be given to a country, such as Argentina in South America, would require from 3 to 5 frequencies spaced properly between 6,000 and 20,000 kilocycles, the proper frequency being used in accordance with its known propagation characteristics.

It has been suggested that these frequencies be used for the purpose of covering portions of the United States. In order to do this each station would be required to use from 3 to 5 different frequencies throughout the period of propagation in order to cover given areas. If each country in the world tried to give this kind of a service it would require more than all the frequencies above 6,000 kilocycles to meet the needs of all nations. Instead of a station being assigned a single frequency, as is done in domestic broadcasting, each station would have to be assigned a multiplicity of frequencies, and instead of the allocation problem being confined to the United States, the interference limitations imposed by stations of the entire world would need to be met.

The nations of the world, realizing this lack of adequate supply of frequencies, have practically all confined their use of these frequencies to broadcast programs destined for reception in other countries. Unfortunately, this has not been confined to the propagation of entertainment programs only, but these programs have also included propaganda and much might be said as to the improper use of such frequencies. However, this is not a technical question.

These frequencies likewise have the same limitations with respect to fading as do the lower frequencies used in broadcasting. The entire service of these frequencies is secondary service and consequently subject to fading and interference from electrical noises. The service can never be as good as the service given by a steady signal from a local station. The limitations of selectivity of receiving sets and distribution of population also apply to this band of frequencies.

From an engineering standpoint it is known what these frequencies can do and what limitations they have. The limitations are natural phenomena and there is nothing that can be done to change the phenomena. By technical advances the characteristics of the devices which transmit and receive them, may be changed but at present there appears no way by which the laws of nature can be changed. With these frequencies, as with the broadcast frequencies, the utmost information concerning the laws of nature must be obtained and applied to the best of our ability to the problems in hand.

Man may not like the consequences of natural laws and the natural limitations of radio propagation, but he must accept them. Man can make and unmake his own laws and limitations, and change them as he desires, but nature makes her laws and they are final; man can learn what they are and use them, but he cannot change them.

# The Dielectric Strength of Noninflammable Synthetic Insulating Oils

By F. M. CLARK
ASSOCIATE AIEE

THE SUBSTITUTION of chlorine for hydrogen in the hydrocarbon molecule produces marked effect not only on the physical and chemical properties, but on the electrical characteristics as well. The compounds so produced present to the electrical engineer a new type of insulating liquid which eliminates many of the problems heretofore inevitably associated with the use of mineral oil. It is the object of this paper to demonstrate the dielectric strength characteristics of such synthetic liquids both alone and in combination with cellulosic insulation.

Although the use of chlorine-containing compounds in the electrical industry is not new, the application of such liquid materials has been limited because of chemical instability. Under the conditions of voltage stress and high temperature normally encountered in the service of transformers, capacitors, cables, and the like, compounds of the chlorinated paraffin hydrocarbon type have not been found to be very satisfactory. With the development of the chlorinated liquid compounds of the cyclic hydrocarbons,[1,2] dielectric compositions have been made available which fully meet the stability requirements. Because of the desire to obtain noninflammability of the liquid as well as to eliminate the explosiveness of the arc-formed gases, the compounds of this type have at least half of the hydrogen atoms present in the original hydrocarbon replaced by chlorine.[3] Only such compounds are discussed in the present paper.

## The General Characteristics of Noninflammable Synthetic Insulating Liquids

The noninflammable synthetic dielectric liquids at present commercially available are, in general, chlorinated derivatives of cyclic organic hydrocarbons. In order to obtain suitable physical characteristics, such as viscosity and low congealing point, blends of chlorinated organic compounds are frequently employed. Among the compounds in commercial use or available for use are the chlorinated derivatives of diphenyl, diphenyl oxide, benzophenone, diphenyl methane, dibenzyl, and benzene. Each of these has its advantages.[4] At present, however, the chief commercial interest lies in compositions containing chlorinated diphenyl and mixtures of chlorinated diphenyl with trichlorbenzene. The properties of 2 such compositions in commercial use as impregnants for capacitors and cables, and as the dielectric and cooling medium for transformers are given in table I. Such compositions are not only noninflammable in themselves, but when decomposed by the electric arc evolve only noninflammable gaseous mixtures.

## The Dielectric Strength of the Liquids

The factors which determine the dielectric strength of insulating liquids are not clearly recognized. Liquid density is without doubt of importance in any homologous series of organic compounds. The difference in density as between two different chemical types of organic liquids, however, does not appear to be of significance in determining the relative dielectric strengths. It has been suggested[5] that the dielectric strength of mineral oils varies with those changes which produce a variation in the dissolved gas content of the liquid. Such a suggestion does not attempt to explain the high dielectric strength of the noninflammable synthetic dielectric liquids described in table I as compared to mineral oil of similar viscosity.

While it is recognized that the dielectric strength of any insulating liquid is distinctly a function of the care used in its preparation and test, the normally expected value for new and unoxidized mineral oil, tested in accordance with the usual practice, is about 30 kv at room temperature. The synthetic liquid dielectrics of table I tested under similar conditions are characterized by a dielectric strength which is from 40 to 50 per cent higher. Such a high dielectric strength becomes only of academic interest unless it can be maintained at a correspondingly higher than oil value during use. Accumulated service and laboratory experience clearly indicates such behavior.

Consideration of the dielectric adaptability of a liquid for any specific application must inevitably include a survey of its chemistry.[8] Detailed chemical analysis of the noninflammable synthetic dielectrics is beyond the scope of this paper, yet for the proper understanding of the materials, consideration of their chemical reactivity cannot be avoided. One of the major factors leading to decreased dielectric strength in liquids is the presence of moisture, moist fibers, gas bubbles, and suspended solids. It is unfortunate that in most of the dielectric applications of mineral oils, oxidation cannot be entirely eliminated. The oxidation of the oil hydrocarbon produces those types of materials which lead to decreased dielectric strength, as for example carbon dioxide gas, water, organic acids, and, if the oxidation is severe, suspended oil sludge. Water coming in contact with oxidized mineral oil may even form a semipermanent emulsion with dangerously low dielectric strength. The noninflammable synthetic

A paper recommended for publication by the AIEE committee on research. Manuscript submitted March 20, 1937; released for publication April 27, 1937.

F. M. Clark is a physicist for the General Electric Company, Pittsfield, Mass.

1. For all numbered references, see list at end of paper.

Table 1. Properties of Noninflammable Synthetic Liquid Dielectrics

| Type | Viscous | Nonviscous |
|---|---|---|
| Use | Capacitors and cables | Transformers |
| Color | Pale yellow | Pale yellow |
| Specific gravity | 1.500 (60/15.5 degrees centigrade) | 1.565 (15.5/15.5 degrees centigrade) |
| Saybolt universal viscosity | 48 seconds at 98.9 degrees centigrade | 54 seconds at 37.8 degrees centigrade |
| Pour point | +10 degrees centigrade | Lower than −32 degrees centigrade |
| Burn point | None | None |

liquids are in marked contrast. Exposed to an oxidizing atmosphere under the most severe conditions, little if any chemical change can be observed. The color and original neutrality are essentially unchanged. No water, gas, or sludge is formed. The initially high resistance to water emulsification is retained with resultant high dielectric stability.

Figure 1 illustrates the marked difference in the dielectric stability of a typical transformer noninflammable synthetic dielectric liquid as compared to the usual mineral transformer oil. The materials were placed each in a clear glass, 5-gallon bottle, maintained at atmospheric temperature, and equipped with an inverted breathing tube open to the atmosphere in such a manner that the direct entrance of water (moisture or rain) was prevented, although free breathing produced as a result of atmospheric temperature changes was allowed. Clear glass bottles were used in order to promote any possible chemical change due to sunlight. Free breathing to the atmosphere was allowed in order that atmospheric moisture might slowly be accumulated in each liquid. Since chemical changes, if present, would include acid formation, liquid darkening, sludge formation, and water accumulation, the relative dielectric stability of the 2 liquids was expected to be demonstrated. As shown in figure 1, the nonoxidizing synthetic liquid gave practically no change in dielectric strength throughout the test exposure. The oxidizable mineral oil showed a slow drop in dielectric strength during the first 16 days of exposure, followed by a severe drop in dielectric strength between the sixteenth and the thirtieth day. At this time, the chemical changes in the oil were sufficiently advanced such that oil acid and sludge had accumulated in the liquid. In both the oil and the noninflammable liquid containers, water had accumulated, on the top of the synthetic liquid and at the bottom of the mineral oil. The test was discontinued after 182 days.

Organic hydrocarbon liquids, if exposed for long periods at high temperature to air and moisture, will oxidize and deteriorate. Under such conditions, the noninflammable synthetic liquids described in this paper show negligible change, either chemically or electrically. Typical results are illustrated in figure 2. The setup consisted of a glass vessel containing the synthetic liquid and connected to a reflux water condenser. Distilled water was added in an amount equal to about 10 per cent of the volume of the synthetic liquid which was heated sufficiently to maintain a slow refluxing of the water. The liquid temperature was approximately 100 degrees centigrade. Metallic aluminum was placed in the body of the liquid dielectric in order to detect any generation of corrosive chlorine formed from the long-time moisture contact in the presence of air. None was observed. The liquid showed no substantial increase in color or acidity. As shown in figure 2, the high dielectric strength of the liquid was maintained.

The superior dielectric strength characteristics of the noninflammable synthetic liquids, when tested with the usual oil-testing procedure, using a 0.1-inch liquid gap, is maintained with greater gap distances. Tests up to a gap distance of 2 inches are illustrated in the data of figure 3.

The dielectric strength of both the noninflammable synthetic liquid dielectric and mineral oil is a logarithmic function of the gap distance. The logarithmic relation, however, changes with increasing gap distance above approximately one inch. This change is illustrated in figure 4. Its technical significance is at present under investigation. For the larger gap distances above one

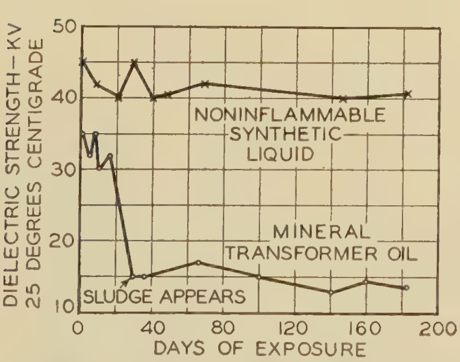



**Figure 1. Comparative stability in dielectric strength of mineral transformer oil and a synthetic noninflammable liquid of similar viscosity**

Dielectric strength tested in accordance with the usual rapidly applied voltage procedure using one-inch brass-disk electrodes spaced 1/10 inch apart

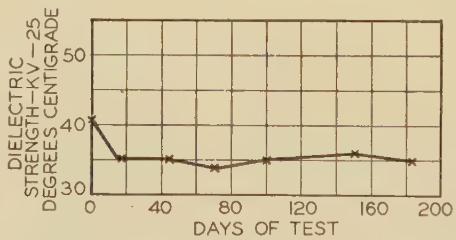



**Figure 2. The dielectric stability of noninflammable synthetic insulating liquids**

Setup: Liquid refluxed with water in presence of aluminum and air. Dielectric strength determined with rapidly applied voltage application using one-inch brass-disk electrodes spaced 1/10 inch apart

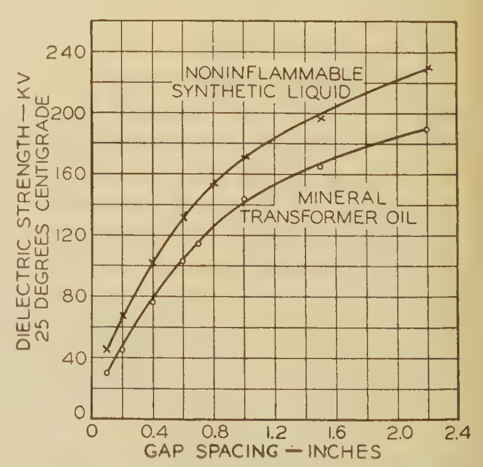



**Figure 3. The dielectric strength-gap distance relation for mineral transformer oil and a noninflammable synthetic insulating liquid of similar viscosity**

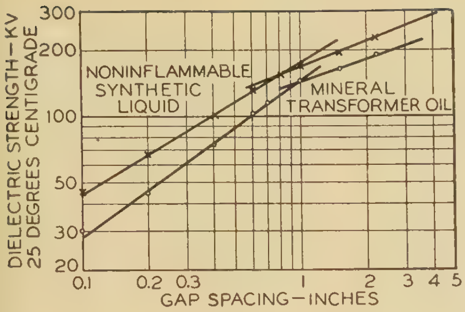



**Figure 4. Showng the logarithmic relation between dielectric strength and gap distance for mineral transformer oil and a noninflammable synthetic liquid of similar viscosity**

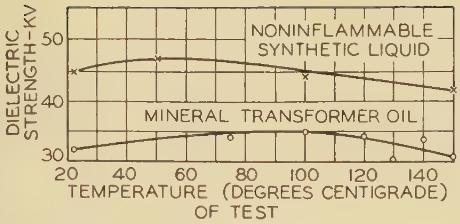



**Figure 5. The comparative dielectric strength of mineral transformer oil and noninflammable synthetic liquid of like viscosity as a function of the testing temperature**

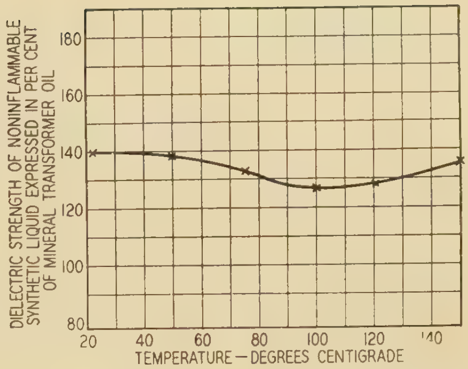



**Figure 6. The increased dielectric strength obtained with the noninflammable synthetic transformer insulating liquid expressed in terms of the dielectric strength of mineral transformer oil as a function of the testing temperature**

inch, the noninflammable synthetic dielectric liquid shows a dielectric strength about 20 per cent higher than that obtained with mineral transformer oil. For the smaller gap distances below one inch, the superiority in dielectric strength of the noninflammable synthetic liquid varies from approximately 20 per cent to as high as 50 per cent as the gap distance is continuously decreased.

Expressed logarithmically for the tests of this survey, the dielectric strength of oil and noninflammable synthetic liquids varies with the gap distance in accordance with equations 1, 2, and 3, in which $T$ indicates gap distance.

For mineral oil below one-inch gap distance:

$$\mathrm{Kv} = AT^{0.70} \tag{1}$$

For noninflammable synthetic liquid dielectrics below one-inch gap distance:

$$\mathrm{Kv} = AT^{0.59} \tag{2}$$

For both oil and noninflammable synthetic liquid dielectrics above one-inch gap distance:

$$\mathrm{Kv} = AT^{0.87} \tag{3}$$

Figure 5 illustrates the effect of temperature change on the dielectric strength of a typical transformer noninflammable synthetic liquid dielectric and mineral transformer oil, each tested with rapidly applied voltage application between one-inch brass disk electrodes spaced $^1/_{10}$ inch apart. As already described in previous papers[6] the dielectric strength of mineral transformer oil increases with increase in temperature to 100 degrees centigrade. The noninflammable synthetic dielectric liquid shows a similar change in dielectric strength with increase in temperature, but reaches its maximum value at about 55 degrees centigrade, above which temperature its dielectric strength decreases in an approximately linear relation to the temperature increase. While at room temperature, the synthetic liquid is approximately 40 per cent higher in dielectric strength than mineral transformer oil, at 100 degrees centigrade the advantage has been reduced to 27 per cent. Above 100 degrees centigrade, the superiority of the noninflammable synthetic liquid again increases due to the more rapid drop in dielectric strength of mineral transformer oil as the temperature is further increased. The relationship is illustrated in figure 6.

It has already been suggested[6] that the change in the dielectric strength of insulating liquids with temperature reflects changes in the liquid-dissolved air content. It is to be observed that the changes in the dissolved air content of the noninflammable synthetic liquid dielectric discussed in these paragraphs predict the change in dielectric strength observed. The dissolved air content at normal atmospheric pressure and the corresponding dielectric strength at 25 degrees centigrade and 100 degrees centigrade for the noninflammable synthetic dielectric liquid under discussion are indicated in the following tabulation:

| | Dissolved Air Content | | Dielectric Strength | |
|---|---|---|---|---|
| | 25°C | 100°C | 25°C | 100°C |
| Mineral transformer oil | 10.0 | 11.3 | 32.0 | 35.0 |
| Noninflammable synthetic liquid | 6.3 | 6.0 | 45.5 | 44.5 |

## The Dielectric Strength of Treated Insulation

The ability of an insulating liquid to impart a high dielectric strength to cellulosic insulation is one measure of its usefulness. It is frequently considered that all insulating liquids possess equal ability to impart dielectric strength to solid insulation unless prevented by exceptional physical characteristics. Since most liquids heretofore investigated have been of petroleum origin, this generalization has been apparently well-founded. With the noninflammable synthetic liquid dielectrics of the type under discussion, however, 2 important changes have been introduced. The first is that the characteristic dielectric strength of the liquid has been raised by more than 20 per cent, depending upon the testing temperature and gap spacing. The second is that the dielectric constant has been materially increased. Over the range of temperature from 25 degrees centigrade to 100 degrees centigrade, the dielectric constant of the noninflammable synthetic

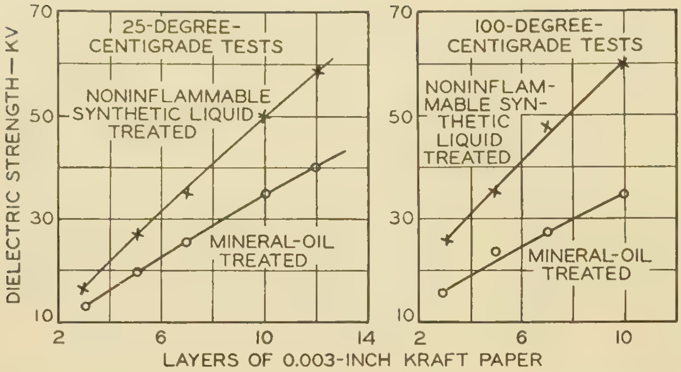
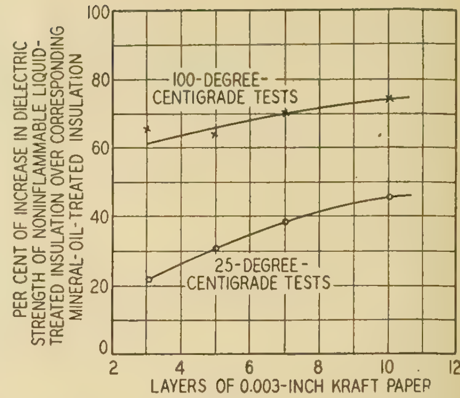



**Figure 7. The comparative dielectric strength of mineral oil and noninflammable synthetic-liquid-impregnated kraft paper**

**Figure 8. The superiority of the noninflammable synthetic-liquid-impregnated 0.003-inch-kraft-paper dielectric expressed in terms of the corresponding mineral-oil-treated dielectric**




Testing temperature —25 degrees centigrade and 100 degrees centigrade, as indicated

Testing procedure—Minute test

Insulation thickness—0.004 inch (8 sheets of insulation)

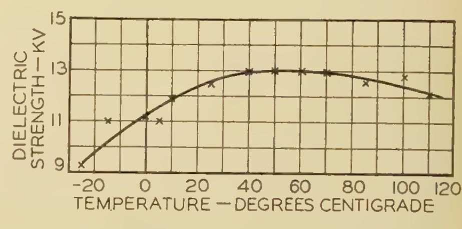



**Figure 9. The dielectric strength-temperature relation for 0.0005-inch-kraft-paper insulation impregnated with the transformer type of noninflammable synthetic insulating liquid**

liquid under discussion varies from 5 to 4, a value more closely approximating that of the cellulose material itself than does the dielectric constant of mineral oil or related hydrocarbon mixtures, the characteristic dielectric constant of which is approximately 2.2. Since liquid-impregnated cellulosic insulation in laminated structures, such as is normally used in commercial dielectrics, is essentially a series arrangement of liquid and solid, the advantage of an equalized dielectric constant as between the liquid and solid is immediately evident. Higher breakdown values for the noninflammable synthetic liquid impregnated cellulosic insulation are to be expected, not only because of the increased dielectric strength of the liquid itself as compared to mineral oil but also because of the more equal stress distribution resulting from the equalization of the dielectric constant of the liquid and the cellulosic base.

Figure 7 illustrates the dielectric strength of 0.003-inch kraft paper impregnated insulation, tested by the "minute test" voltage procedure, both at 25 degrees centigrade and at 100 degrees centigrade. The presence of the synthetic liquid increases the breakdown of the paper insulation as compared to the corresponding oil-treated value, the increase in breakdown increasing as the total thickness of the pad tested is increased. This is illustrated in figure 8.

Figure 9 illustrates the temperature effect on dielectric strength for noninflammable synthetic liquid-impregnated insulation, tested by the "minute test" procedure from −20 degrees centigrade to +100 degrees centigrade. The insulation in this case consists of 8 layers of 0.0005-inch kraft capacitor paper.

The advantageous dielectric strength characteristic of insulation impregnated with the noninflammable synthetic insulating liquid is undoubtedly related to thermal phenomena. Under conditions which prevent serious heat accumulation effects, the dielectric strength of mineral oil-treated insulation or untreated insulation is a logarithmic function of the thickness and approaches the first power function of the thickness factor. With test conditions which allow greater thermal effect, although the logarithmic relation is sustained, the dielectric strength increases at a decreased function of the insulation thickness.[7] The following relationships have been established for insulation tested in the form of flat pads:

Untreated kraft paper at 25 degrees centigrade, rapidly applied voltage

$$\text{Kv} = AT^{0.92\text{ to }1.0} \qquad (4)$$

Untreated kraft paper at 25 degrees centigrade, minute test voltage

$$\text{Kv} = AT^{0.92\text{ to }1.0} \qquad (5)$$

Mineral-oil-treated kraft paper at 25 degrees centigrade, rapidly applied voltage

$$\text{Kv} = AT^{0.90\text{ to }0.95} \qquad (6)$$

Mineral-oil-treated kraft paper at 25 degrees centigrade, minute test voltage

$$\text{Kv} = AT^{0.75} \qquad (7)$$

The dielectric strength data of figure 7 are also a logarithmic function of the insulation thickness. The "minute test" breakdown at 25 degrees centigrade for 0.003-inch mineral-oil-treated kraft paper agrees well with the previously established relation (equation 7), breakdown varying with thickness in accordance with equation 8:

$$\text{Kv} = AT^{0.76} \qquad (8)$$

The previous publication,[7] however, did not demonstrate that when the temperature of the test is increased, the logarithmic relation correlating breakdown and insulation thickness changes, again reflecting the effect of heat accumulation. The data of figure 7 and figure 10 describing the dielectric strength-thickness relation for mineral-oil-treated kraft paper at 100 degrees centigrade indicate the following expression:

$$\text{Kv} = AT^{0.66} \qquad (9)$$

In table II, rapidly applied test breakdown data are given for impregnated kraft paper tested at 25 degrees centigrade. Complete data covering a wide range of insulation thicknesses are not illustrated. Such studies, however, clearly substantiate the logarithmic relation between dielectric strength and insulation thickness whether the kraft paper be impregnated and tested under mineral oil or the synthetic noninflammable liquid. The formula established from these studies relating the dielectric strength under rapidly applied tests at 25 degrees centigrade for both types of impregnants is given in equation 10:

$$\mathrm{Kv} = AT^{0.90 \text{ to } 0.95} \tag{10}$$

The similarity in the dielectric strength-thickness relation for kraft paper insulation impregnated with mineral oil and the synthetic liquid when tested at 25 degrees centigrade with rapidly applied voltage procedure is to be expected since under these conditions heat effects are negligible. When, however, longer time voltage tests are used the kraft paper insulation impregnated with the noninflammable synthetic liquid dielectric shows a closer approach to a linear relation of thickness and dielectric strength than that established for mineral oil-treated insulation. This is illustrated in figure 10. While in this instance the dielectric strength at high temperature is a decreased logarithmic function of thickness, the effect of change in insulation thickness for the synthetic liquid treated insulation always more closely approximates a linear relation than that observed for the corresponding mineral-oil-treated dielectric. This is indicated in the following formulas set up for 0.003-inch kraft paper impregnated with the noninflammable synthetic liquid dielectric and tested in accordance with minute test voltage application procedure:

At 25 degrees centigrade, $\mathrm{Kv} = AT^{0.94}$ (11)

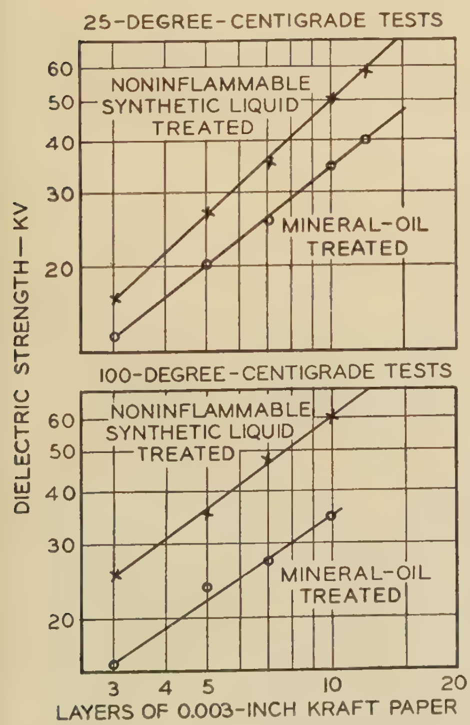



**Figure 10. Illustrating the logarithmic relation between dielectric strength and thickness for 0.003-inch-kraft-paper insulation impregnated with mineral transformer oil and synthetic noninflammable dielectric liquid of like viscosity**

Testing procedure—Minute test (data based on figure 7)

**Table II. The Comparative Rapidly Applied and Minute-Test Dielectric Strength of Impregnated Kraft Paper**

Test temperature—25 degrees centigrade
Voltage applied—60 cycles
Insulation—0.003-inch impregnated kraft paper
Test medium—Same as impregnating medium

| | Average Dielectric Strength | | |
|---|---|---|---|
| | Rapidly Applied Voltage, (Kv) | Minute Test Voltage, (Kv) | Per Cent Decrease Due to Extended Time |
| Oil impregnated—10 layers | 41.0 | 35.0 | 14.7 |
| Noninflammable synthetic-liquid-impregnated—10 layers | 55.5 | 50.0 | 9.7 |
| Oil impregnated—15 layers | 59.0 | 47.0 | 20.3 |
| Noninflammable synthetic-liquid-impregnated—15 layers | 80.0 | 72.0 | 10.0 |

At 100 degrees centigrade, $\mathrm{Kv} = AT^{0.71}$ (12)

The dielectric strength of mineral-oil-treated insulation decreases with the duration of voltage application. With the so-called "life test," in which the voltage application extends over weeks and months, this effect may be produced by voltage or by heat accumulation, both of which result in chemical deterioration in the dielectric assembly. Such effects are not susceptible to easy demonstration under laboratory conditions. Data available, however, indicate clearly that the marked chemical stability of the noninflammable synthetic dielectric liquids as compared to the susceptibility of the hydrocarbon oils to oxidation and other forms of chemical change is reflected in the greater electrical stability of the treated insulation.

Test temperature—25 degrees centigrade

Voltage application—Minute test procedure

Test form—Flat pads

Electrodes—Aluminum foil

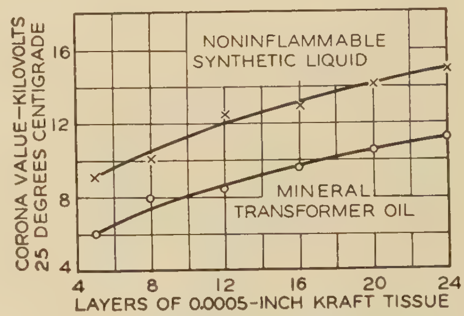



**Figure 11. The visual corona-formation point for mineral-transformer-oil-treated and synthetic-liquid-treated 0.0005-inch-kraft-paper dielectric**

Voltage application—Minute test procedure

Dielectric thickness—0.004 inch

Electrodes—Aluminum foil

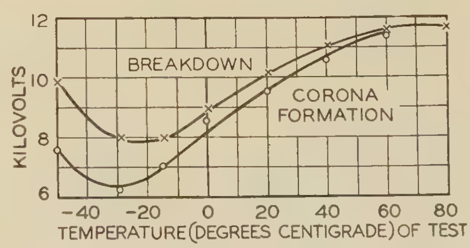



**Figure 12. Corona formation and breakdown of noninflammable synthetic-liquid-treated 0.0005-inch-kraft paper as a function of the testing temperature**

The dielectric superiority of the noninflammable synthetic-liquid-treated insulation is indicated even under conditions of test in which air and oxygen are carefully excluded in order to eliminate mineral-oil-oxidation effects. Thus in one typical group of tests, dielectric assemblies were prepared each consisting of aluminum electrodes separated by 3 sheets of 0.0004-inch kraft tissue. The electrodes were $2^{7}/_{8}$ inches wide and 94 feet long. The rolled assembly was vacuum dried, impregnated and tested in a gas-free hermetically-sealed container. The following results clearly indicate the superiority of the synthetic-liquid-treated insulation even when tested under the most favorable mineral oil conditions:

| Dielectric Treated With | Mineral Oil | Noninflammable Synthetic Liquid |
|---|---|---|
| Number assemblies tested | 40 | 40 |
| Voltage applied (60 cycles) | 880 | 880 |
| Volts per mil | 733 | 733 |
| Ambient testing temperature | 30 degrees centigrade | 30 degrees centigrade |
| First dielectric failure | 1 day | 17 days |
| Total dielectric failures in 10 days | 7 ($17^{1}/_{2}$ per cent) | 0 (0 per cent) |
| Total dielectric failures in 25 days | 12 (30 per cent) | 1 ($2^{1}/_{2}$ per cent) |
| Total dielectric failures in 50 days | 15 ($37^{1}/_{2}$ per cent) | 2 (5 per cent) |
| Total dielectric failures in 70 days | 16 (40 per cent) | 2 (5 per cent) |

Laboratory demonstration of the greater time-voltage stability of the noninflammable liquid as compared to the mineral-oil-treated dielectric is also illustrated by the usual time-voltage relation in which the voltage is continuously applied for periods from one second to 1 or 2 hours. Reference to data already presented will serve to indicate the comparison. In table II, the 10-second breakdown (called "rapidly applied test") is compared to the so-called "minute test" procedure, in which the voltage is slowly raised over a period of about 10 minutes. In general, the effect of lengthened time of voltage application is less on the noninflammable synthetic liquid-treated insulation. Under the conditions outlined, a decrease in breakdown value of 10 per cent appears to be characteristic of kraft paper insulation impregnated with the noninflammable synthetic liquid dielectric. This compares to a corresponding average decrease of 17 per cent characteristic of the same dielectric when mineral-oil impregnated.

## Visual Corona Formation in the Treated Dielectric

The dielectric failure of insulation is inevitably preceded by the formation of corona in the liquid layer. With mineral-oil-treated insulation, because of the difference in the dielectric constants of the oil and the cellulosic insulation, coupled with the breakdown characteristic of the oil itself, corona may appear at relatively low voltage stress. With 0.0005-inch kraft-paper tested by the "minute test" procedure, the corona formation point of the noninflammable synthetic liquid-treated dielectric, depending upon the thickness of insulation tested, is from 30 per cent to 50 per cent higher than the corresponding corona formation point in the mineral-oil-treated dielectric. Figure 11 illustrates the corona formation value for mineral-oil-treated 0.0005-inch kraft paper as compared to similar insulation impregnated with noninflammable synthetic liquid of similar viscosity. The corona formation point is described as the voltage at which visual discharge appears at the edges of the aluminum foil electrodes used in this test setup, all tests being carried out under the same medium used for the impregnation of the kraft paper. With temperature increase, the corona formation of the noninflammable synthetic liquid-treated dielectric increases. Figure 12 shows the corona formation value in its relation to the ultimate "minute test" breakdown as the temperature is changed from −50 degrees centigrade to +80 degrees centigrade. With temperatures higher than 60 degrees centigrade to 80 degrees centigrade, the corona-formation voltage increases to the extent that it blends with the breakdown voltage and is visually indistinguishable therefrom. As the temperature is decreased below room temperature, the breakdown and the corona formation voltage do not decrease indefinitely but reach a minimum value in the range of about −30 degrees centigrade. Both values increase with further decrease in temperature. Such changes invariably accompany a change in physical state, liquid to solid, and are normal behavior of mineral oils as well as other dielectric liquids.

## Summary

The development of synthetic noninflammable chlorinated liquids of the aromatic hydrocarbon type places in the hands of the engineer a chemically stable material of high dielectric strength and possessing a dielectric constant approximately equal in value to that of cellulose itself. This insures a more equitable stress distribution in the composite insulation assembly normally used in commercial practice. The result is an increase in dielectric breakdown and related phenomena. No fixed relation defining the superiority of the synthetic noninflammable liquid or liquid-treated insulation is possible, since variation in test conditions changes the relative dielectric values. In general, however, the data indicate an advantage in favor of the synthetic liquid and liquid-treated insulation equal to at least 20 per cent of the corresponding mineral-oil value.

## References

1. The trade name "Pyranol" has been assigned to these compounds.

2. Development and Application of Synthetic Liquid Dielectrics, F. M. Clark. American Electrochemical Society *Transactions*, volume 65, 1934, pages 59–70.

3. F. M. Clark, U.S. Patent numbers 1,931,455; 1,931,373 (Oct. 17, 1933).

4. F. M. Clark et al, U.S. Patent numbers 2,041,594 (May 19, 1936); 2,033,612 (March 10, 1936); 2,012,301 (August 27, 1935); 2,012,302 (August 27, 1935); 1,999,004 (April 23, 1935); 1,944,730 (January 23, 1934).

5. Dielectric Strength of Mineral Oils, F. M. Clark. Electrical Engineering, January 1935, pages 50–55.

6. The Electrical Breakdown of Liquid Dielectrics, F. M. Clark. *J.* Franklin Inst., volume 216 for October 1933, pages 429–58. The Role of Dissolved Gases in Determining the Behavior of Mineral Insulating Oils, F. M. Clark. *J.* Franklin Inst., volume 215 for January 1933, pages 39–67.

7. The Dielectric Strength-Thickness Relation in Fibrous Insulation, F. M. Clark and V. M. Montsinger. *General Electric Review*, volume 28 for May, 1925, pages 286-90.

8. The Development of Noninflammable Dielectric Organic Compounds, F. M. Clark. A paper accepted for publication in *Industrial and Engineering Chemistry*.

# Application of Arresters and the Selection of Insulation Levels

By J. H. FOOTE
FELLOW AIEE

J. R. NORTH
MEMBER AIEE

FOR many years, the insulation strength of power transformers and other electrical equipment was determined chiefly by the performance in service. When failures occurred, the insulation was made heavier at the points of weakness, and gradually the number of weak points was reduced in the particular lines of equipment and ratings involved. When new lines or ratings were initiated, operating experience was frequently necessary to perfect the design. Little information was available regarding the insulation strength of equipment under impulse conditions, and there was practically no selected co-ordination between the equipment strength and the performance of surge protective equipment.

The principal cause of equipment failures has been lightning, and much attention has been given during the past few years to the study of lightning phenomena and the behavior of insulation material under lightning stress. At the same time, the study of protective equipment has made available a knowledge of its behavior under lightning surge conditions. Great strides have been made in this direction, so that it is now possible to select insulation levels with a degree of confidence as to subsequent performance, provided that proper correlation of these phenomena and behavior characteristics is effected.

This paper describes a method of selecting the required insulation levels of transformers and other power system equipment according to the performance of the protective equipment.

A brief review of some of the important phases of the problem will first be given in order that the method proposed for the selection of insulation levels may be readily understood.

The most important factors are:

(*a*) The magnitude and duration of the overvoltages to which the equipment may be subjected

(*b*) The volt-time insulation characteristics of the equipment

(*c*) The performance characteristics of available protective equipment

## Overvoltages

Transformers and other power system equipment may be subjected to overvoltages due to:

(*a*) Switching surges and abnormal power system conditions

(*b*) Lightning

Switching surges are usually of relatively long duration, but their magnitudes generally do not exceed 3.5 times normal voltage.[1] On many systems, they are less than 2 times normal voltage. Dynamic overvoltage due to hydroelectric generator runaway or other abnormal unloading conditions may reach values as high as 2 times normal. Apparatus designed in accordance with AIEE alternating voltage dielectric tests has proved to be entirely adequate for such overvoltages arising from system operation.

Lightning is considered to be the principal source of insulation failure because of the very high values of voltage and the steep wave fronts involved. Lightning voltages may be the result either of a direct stroke or a traveling wave, and the effect on insulation depends upon the magnitude, the duration, and the rate of rise and decay of the surge potential. It is apparently more economical and practical to take advantage of the protective equipment available and to utilize apparatus of an insulation strength properly co-ordinated with this protective equipment than to attempt to build apparatus in the present operating voltage ranges which will be able to withstand lightning surges without the use of some auxiliary protective device, either separate from or integral with the apparatus.

## Protective Equipment

The fundamental duty of a surge voltage protective device is to discharge any surge successfully and to limit the voltage to values well within the impulse strength of the equipment. In this discussion, the protective equipment will be assumed to include lightning arresters properly applied, supplemented by gaps on line terminals and by direct stroke shielding.

### Lightning Arresters

A lightning arrester is a device which has the property of reducing the voltage of surges applied to its terminals, is capable of interrupting follow current (if present), and restores itself to its original operating condition without causing a disturbance on the system. A lightning arrester, due to its rapid breakdown or gap flashover and the relatively low voltage across it during discharge provides both short time and long time protection to insulation except for some direct strokes.

Typical protective characteristics of modern lightning arresters, based on information as available and including impulse breakdown voltages and the voltage across the arrester during discharge of surge currents of various magnitudes, are presented in table I. Complete performance characteristics of line-type arresters are presented in the report of the AIEE lightning arrester subcommittee.[2]

A paper recommended for publication by the AIEE committees on electrical machinery, protective devices, and power transmission and distribution. Manuscript submitted March 24, 1937; released for publication April 12, 1937.

J. H. Foote is supervising engineer and J. R. North is general engineer with The Commonwealth and Southern Corporation, (N. Y.) Jackson, Mich.

1. For all numbered references see list at end of paper.

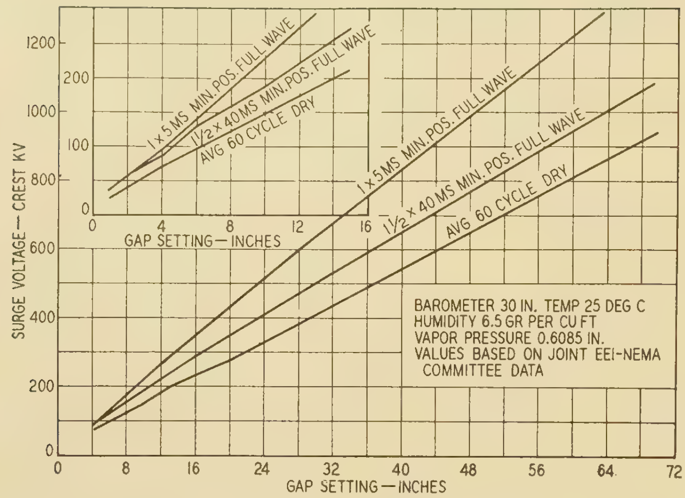



**Figure 1. Rod gap flashover voltages**

### Gaps

Various types of special gaps, such as the control gap, deion gap, and expulsion gap, have been developed. These have particular operating characteristics which govern their application and give varying degrees of protection.

The rod gap which has been extensively used in the past few years as a device for applying impulse tests on transformers and for co-ordination work in the laboratories, is defined as one consisting of $^1/_2$-inch square-cornered square-cut rods coaxially spaced and overhanging their supports at least one-half the gap spacing, and mounted on conventional insulators giving a height of 1.3 times the gap spacing plus 4 inches ($\pm$10 per cent tolerance) above the ground plane. Figure 1 shows the 1.5x40 microsecond, the 1x5 microsecond minimum flashover, and the 60-cycle characteristics of this rod gap. Figure 2 shows the approximate volt-time characteristics at various spacings. The protection afforded by rod gaps is discussed in another paper presented at this symposium.[3]

### Direct Stroke Protection

Shield wires or ground wires have proved themselves very effective for direct stroke protection when properly located and adequately grounded.[4] Shielding is of principal value in the protection of high-voltage lines and equipment against direct strokes and may be justified when the investment is proportionately high.

## Insulation Characteristics of Equipment

Various materials having markedly different insulation strength characteristics are used in electrical equipment. For example, a transformer consists of laminated insulation, solid insulation, oil, porcelain, and clearances in air. The volt-time characteristics of laminated and solid insulation are relatively flat, approaching the characteristics of a sphere gap. On the other hand, the volt-time characteristics of porcelain are approximately the same as rod gaps and show time lags at short time intervals. This is illustrated by figure 3. This disparity between the characteristics of the solid insulation and the bushing or rod gap necessitates that an insulation co-ordination study be made on a volt-time basis with full recognition of short time as well as long time phenomena.

Volt-time characteristics of apparatus insulation are not as yet generally available. It has, therefore, been necessary to study insulation levels largely in terms of voltages corresponding to some particular specified test wave condition. As a matter of convenience, the manufacturers have been expressing these insulation levels largely in terms of rod gaps, corresponding to some particular specified test wave condition. This has proved inadequate and basic insulation levels have recently been set up in terms of the minimum impulse flashover voltage on a $1^1/_2$x40 microsecond wave under standard conditions.[5] The latest authentic data available regarding the impulse strength of transformers is presented in reports by the AIEE transformer subcommittee.[6,7]

## Selection of Insulation Levels

An electrical station is composed of a number of component parts, i.e., transformers, circuit breakers, bus, etc., each including various types of insulation—air, oil, porcelain, and other materials. In order to render such a station as immune as practicable to transient voltage disturbances there must be a definite relationship between

**Table I. Typical Performance of Modern Lightning Arresters**

| Arrester Rating (RMS Kv) | Arrester Gap Breakdown (Surge Crest Kv) | Voltage Across Arrester During Discharge (Crest Kv) | | |
|---|---|---|---|---|
| | | 1,500 Amp | 3,000 Amp | 5,000 Amp |
| **Protective Ability** | | | | |
| **Line Type** | | | | |
| 3 | 17 | 11 | 13 | 15 |
| 6 | 35 | 21 | 24 | 27 |
| 9 | 49 | 31 | 36 | 40 |
| 12 | 58 | 40 | 47 | 52 |
| 15 | 66 | 51 | 59 | 65 |
| 20 | 80 | 70 | 78 | |
| 25 | 100 | 88 | 97 | |
| 30 | 115 | 105 | 115 | |
| 37 | 140 | 130 | 145 | |
| 50 | 180 | 175 | 195 | |
| 60 | 215 | 215 | 235 | |
| 73 | 270 | 260 | 285 | |
| **Station Type** | | | | |
| 3 | 14 | 9 | 10 | 11 |
| 6 | 24 | 18 | 20 | 21 |
| 9 | 36 | 27 | 30 | 32 |
| 12 | 41 | 36 | 43 | 50 |
| 15 | 51 | 45 | 55 | 63 |
| 20 | 70 | 59 | 66 | 75 |
| 25 | 85 | 74 | 86 | 100 |
| 30 | 100 | 91 | 110 | 127 |
| 37 | 125 | 110 | 130 | 150 |
| 50 | 170 | 149 | 175 | 200 |
| 60 | 205 | 182 | 220 | 250 |
| 73 | 250 | 220 | 265 | 300 |
| 97 | 330 | 290 | 350 | 400 |
| 121 | 410 | 360 | 440 | 500 |
| 145 | 490 | 430 | 530 | 600 |
| 169 | 570 | 500 | 620 | 700 |
| 242 | 820 | 720 | 890 | 1,000 |

**Thermal Ability**

The thermal ability is a function of the magnitude of the current and its duration. The line type arresters can withstand surge currents of 2,000–3,000 amperes crest and the station type arresters 10,000 amperes crest with surges of relatively long tails. These arresters can withstand a limited number of surges of higher current values provided they are of shorter duration.

the characteristics of the protective devices and the insulation strength of the equipment. Since overvoltages due to lightning are conceded to be the most serious source of trouble, then logically the characteristics of the surge protective equipment will form the criterion. *The insulation level of apparatus must be above the maximum surge voltage presumed to be allowed by the protective device on a volt-time basis over the range of time selected.*

The transformer is usually the most important piece of equipment in a station, both from the standpoint of cost and of service continuity. Furthermore, the major insulation in a transformer has practically a flat time-lag characteristic (figure 3) and this tends to make its protection from surges having high amplitudes and steep fronts a more serious problem than that of air, oil, or porcelain insulation. The protection of the transformer insulation has, therefore, been considered to be of prime importance in determining a proper insulation level.

Having available performance data on protective equipment and having evaluated the marginal factors, the determination of insulation levels is chiefly a matter of the selection and application of the protective equipment. The protective performance of modern lightning arresters has been selected as a suitable basis for the initial establishment of a series of protected insulation levels. Arresters generally have the following characteristics which are of value in this connection:

(*a*) A regular series of voltage ratings, including the distribution voltages, have been standardized.

(*b*) The performance characteristics as indicated in table I have been determined as typical, and it is assumed that the devices produced by the principal manufacturers have characteristics sufficiently similar to render them suitable for general application.

(*c*) The performance characteristics are such as to approximate the volt-time characteristics of transformer insulation.

(*d*) The performance characteristics are unaffected by weather and do not greatly change in general character with considerable change in voltage rating.

## Application of Lightning Arresters

The principal factors in the selection of the rating of a surge protective device, such as a lightning arrester or a gap, are:

(*a*) The maximum dynamic voltage which may occur between sound phase and ground under any fault conditions. The device must withstand this voltage without failure.

(*b*) The efficacy of the protective device in maintaining a low protected level and at the same time meeting satisfactorily the system operating requirements. The impulse volt-time characteristics must be below that of the equipment to be protected.

(*c*) The surge current which must be satisfactorily discharged. The thermal ability must be adequate for the currents expected.

The voltage rating of an arrester represents the maximum dynamic voltage which the arrester can withstand continuously and which it can interrupt after discharge. The arrester rating must, therefore, be greater than the maximum dynamic voltage which may occur between the arrester terminals during disturbances, allowing for the power system neutral being isolated, or grounded, as the case may be, and considering the actual maximum operating voltage. Allowance must also be made for the voltage recovery rate and any overvoltage conditions which may exist due to the overspeeding of hydroelectric generators, etc. The protection afforded by a lightning arrester is approximately proportional to its voltage rating and, therefore, it is important to use an arrester of as low a voltage rating as possible. Table II presents the general

**Table II. Typical Application of Lightning Arresters**

| System Voltage Classification | Approx. Range System Operating Voltage | Preferred Arrester Rating (Maximum Line-Ground Voltage, Kv): Neutral Not Effectively Grounded | Neutral Effectively Grounded |
|---|---|---|---|
| 2,400 | 2,200– 2,650 | 3 | 3 |
| 4,160Y | 3,800– 4,600 | 6 | 3 |
| 4,800 | 4,400– 5,300 | 6 | 6 |
| 7,200 | 6,600– 7,950 | 9 | 6 |
| 8,660Y | 7,600– 9,200 | 12 | 6, 9 |
| 12,000 | 11,000–13,000 | 12, 15 | 9, 12 |
| 13,200 | 12,100–14,300 | 15 | 12 |
| 14,400 | 13,200–15,000 | 15 | 12 |
| 23,000 | 20– 25 kv | 25 | 20 |
| 34,500 | 30– 37 kv | 37 | 30 |
| 46,000 | 40 –48 kv | 50 | 37 |
| 69,000 | 60– 72 kv | 73 | 50, 60 |
| 115,000 | 100–120 kv | 121, 132 | 97 |
| 138,000 | 120–144 kv | 145, 156 | 121 |
| 161,000 | 140–168 kv | 169, 180 | 121, 145 |
| 230,000 | 200–240 kv | 242 | 200 |

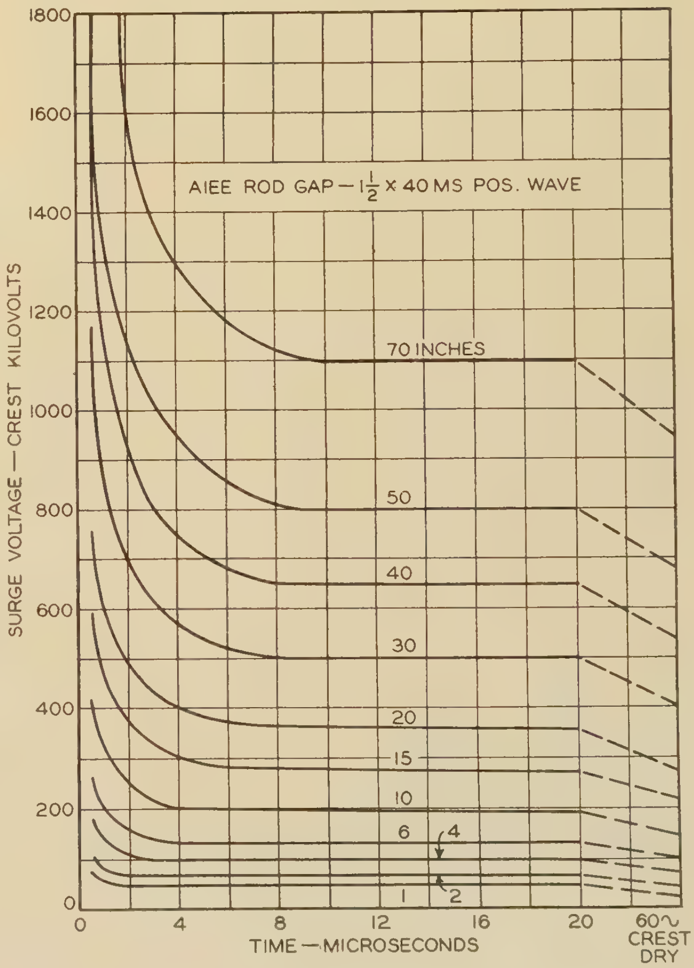



Figure 2. Rod gap volt-time curves

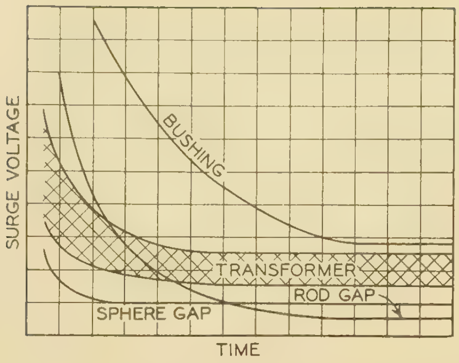



**Figure 3. Relative volt-time curves**

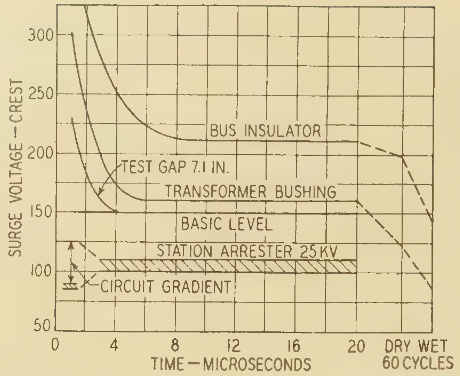



**Figure 4. Station insulation—25-kv class—volt-time curves**

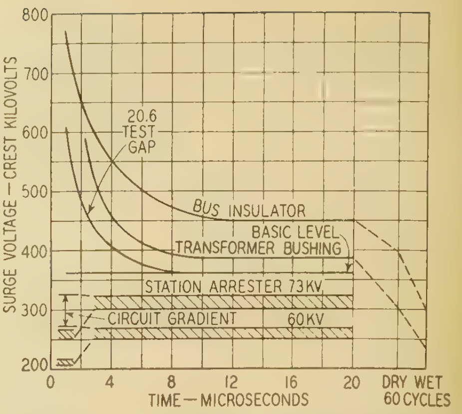



**Figure 5. Station insulation—69-kv class—volt-time curves**

application of arresters to systems in the various voltage classifications.

## Dynamic Voltage

The normal "full voltage" rated arrester is designed to operate on an ungrounded or isolated neutral system where the voltage existing between line and ground may at times equal the normal line-to-line voltage. The arrester rating is generally 5 per cent or more above the maximum operating voltage. Under favorable conditions where the system neutral is effectively grounded, better protection may be obtained by the use of an arrester having a reduced voltage rating, provided the upper limit of dynamic voltage is not exceeded under any operating condition. In the past "grounded neutral" arresters have had voltage ratings approximately 80 per cent of the "full rated" arresters. This gave a wide margin above the normal system line-to-neutral voltage to allow for fault voltages, etc.

For the purpose of determining the allowable arrester voltage rating, the maximum dynamic voltage which may occur during fault conditions between the sound phases and ground may be calculated by the method of symmetrical components. Under certain conditions, a 2-line-to-ground fault may be slightly more severe than a single line-to-ground fault.

For a single line-to-ground fault, Wagner and Evans[8] have shown that:

$$E_b = \frac{\sqrt{3}E_g}{2}\left[\frac{\sqrt{3}(Z_0 + R) + j(Z_0 + 2Z_2 + 3R)}{Z_0 + Z_1 + Z_2 + 3R}\right]$$

where

$E_b$ = voltage between sound phase and ground
$E_g$ = normal line to neutral voltage
$Z_1, Z_2, Z_0$ = sequence impedance to point of fault
$R$ = fault resistance

Arresters of reduced voltage rating should not be applied except where the neutral is "effectively grounded" and the following conditions are met:

(*a*) The neutral of that portion of the system must be grounded at all times and under all operating conditions.

(*b*) The ratio of zero-sequence impedance (including neutral impedance and fault resistance) to positive-sequence impedance or negative-sequence impedance ($Z_0/Z_1$ or $Z_0/Z_2$) must be equal to 2 or less under maximum fault conditions. Due consideration must be given to the circuit impedance as affected by sequential operation of circuit breakers at the ends of a line.

(*c*) The arrester voltage rating must be at least 10 per cent above the calculated maximum sound phase voltage to ground. In general it will be found that

if $Z_0/Z_1$ = 2 or less, an 80 per cent arrester may be used
if $Z_0/Z_1$ = 1 or less, a 70 per cent arrester may be used

These latter percentages should be applied to the *maximum* line-to-line operating voltage in determining the allowable arrester rating.

## Surge Currents

Considering traveling wave phenomena, it would be possible to calculate the magnitude of the surge discharge currents through the arrester for the various combinations of line and station insulation which may be encountered. These calculations, however, involve a number of indeterminate factors, including the surge impedance to ground, the magnitude and the wave shape of the surge, etc., and it is not generally considered feasible to make such calculations for each individual case. In the present discussion, the surge discharge current through station type arresters has been taken at 5,000 amperes crest and for line type arresters at 3,000 amperes crest. These values appear to be reasonably moderate in view of available field data[9,10] regarding lightning arrester surge currents. Furthermore, the voltage across the arrester during discharge does not increase in proportion to the surge current.

## Marginal Requirements

The typical performance of arresters, as given in table I, applies only to the arresters themselves, without any tolerances or margins. It must be realized, however, that with any protective device, an adequate margin must be provided above its performance characteristic to allow for manufacturing tolerances, different types of installations and to insure proper selectivity between the protective performance of the device and the apparatus insulation. The necessary margin is thus affected by a number of factors and should cover both long time im-

pulses and short waves of steep front and high crest.

The following tolerances and marginal items have been considered in this analysis with values as indicated:

(*a*) *Tolerances* in performance characteristics of arrester. Based upon manufacturer's information, these have been taken as:

Gap breakdown voltage = plus 5 per cent to 25 per cent

*IZ* drop across arrester during discharge of specified current = plus 5 kv + (5 per cent to 15 per cent)

(*b*) Effect of *distance and potential gradient* during surge conditions which may generally exist between the protective device and the apparatus on the basis of modern station layouts. The capacitance of station equipment will be effective in reducing the slope of the incoming surge wave. In the larger high-voltage stations this mitigates against the higher reflected surge voltages and complete double voltage reflections would not be expected unless the station capacity were very small and the station located at the terminal of a line.

The possibility of flashover occurring on the front of the wave, rather than on the tail of the wave as considered in the recent AIEE test procedure using waves of moderate crest, has been taken into account by considering steep wave fronts and both the short time and long time characteristics of insulation and protective devices. Considering the magnitudes of surge voltages and the reflection effects which may reasonably be expected, it appeared that a short time potential gradient of one kv per foot should be adequate allowance for distance, arrester connections, etc. Arresters to be effective should be located as close as possible to the apparatus being protected. In the case of 2,400-volt and 4,800-volt pole-mounted units, the distance between the arrester and the equipment has been taken as 4 circuit feet, with a gradual increase up to 150 circuit feet for the 240-kv class installed in stations.

(*c*) *Selectivity Margin.* It is necessary to provide an adequate margin, both with respect to time and voltage, to insure that the protective device shall function properly before insulation breakdown or damage may occur. There is apparently little definite information available pertaining to the margins which may be necessary. After reviewing past operating experience and correlating the performance of arresters in service with the information available regarding existing insulation levels, it has been concluded that a selectivity margin of some 30 kv to 40 kv (in addition to manufacturing tolerances and circuit gradient) is the minimum which may be used in the transmission-voltage classes.

## Protected Levels

In this analysis, arresters have been utilized on the basis of the voltage rating being approximately equal to the system line-to-line voltage, i.e., the use of a full rated arrester. The actual application of an arrester on a particular power system should ordinarily be on the basis of using one rated as low as permitted by the maximum dynamic voltage which might exist between sound phases and ground as previously described and the protection would be proportional to the voltage ratings shown.

Table III presents an analysis of the performance characteristics of station and line type arresters and includes the various marginal values which have been described. The terms "short" and "long" coupling have been used to designate the location of the arrester relative to the transformer being protected.

Figures 4 and 5 illustrate the arrester performance and station equipment insulation levels on a volt-time basis with a $1^1/_2$x40 microsecond minimum positive wave. Figure 4 assumes a 23-kv system requiring a 25-kv arrester. This arrester will have a gap breakdown potential of 85–89 kv, and the breakdown will take place in approximately one-half microsecond. The voltage across the arrester when discharging 5,000 amperes will be 100–110 kv. With manufacturing tolerances and with the circuit gradient given in table III, there exists a net selective margin between the basic insulation level and the arrester performance of 27 kv to 40 kv. In figure 5 the performances of 60-kv and 73-kv arresters are compared with the volt-time characteristics of 69-kv equipment, basic level, and with the AIEE test rod gap of 20.6 inches. It will be noted that the net selective margins between the basic level and the arrester amount to 35 kv to 40 kv for the full rated 73-kv arrester and 80 kv to 92 kv for the 60-kv arrester.

Figure 6 shows the relation between the recently agreed upon basic insula-

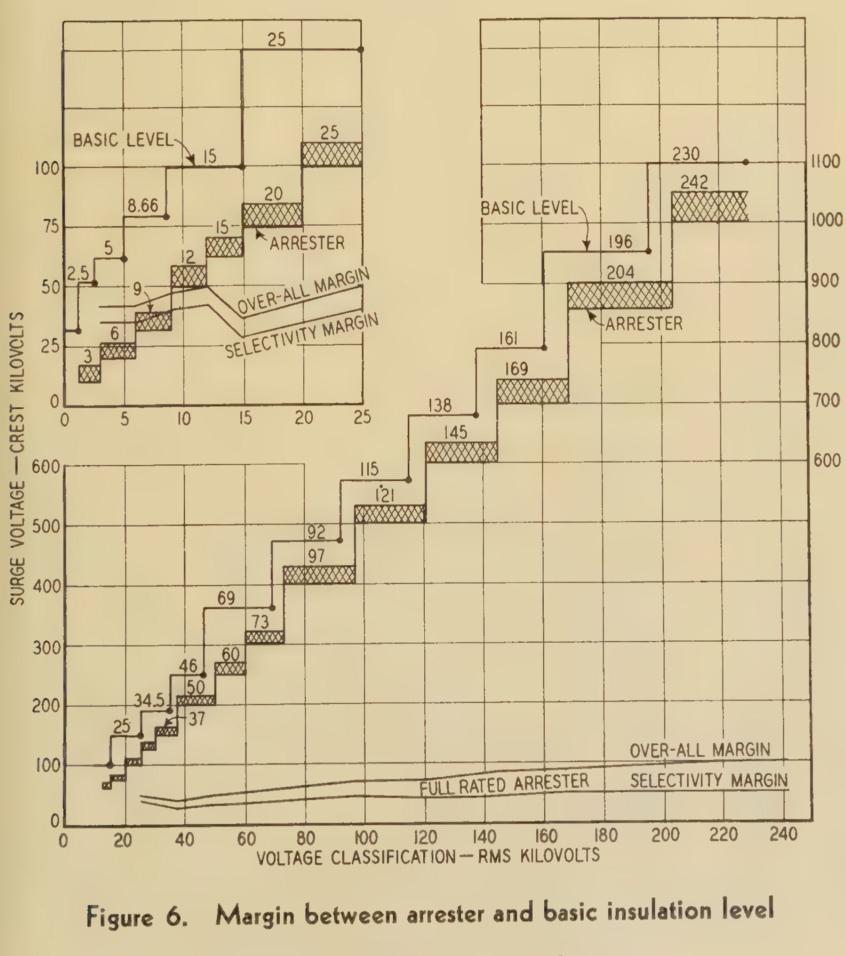



**Figure 6. Margin between arrester and basic insulation level**

Station-type arrester; current = 5,000 amperes

tion levels[5] and arrester performance when discharging 5,000 amperes surge current. The margin between the arrester performance and the long time insulation level of equipment will generally be greater than is indicated by this analysis because the surge currents will not be maintained at high values for long periods of time. Incoming surges which produce these heavy currents will generally have caused flashovers out on the line and will thus be chopped. The margin at short time intervals will also be somewhat greater than indicated because the insulation strength of apparatus is inherently higher than the basic level at short time intervals. These margins between the arrester performances and the basic levels generally range from 30 kv to 100 kv in the various voltage classifications, as shown in table III. In certain cases, such as in the 15-kv classification, the margins are relatively small. In cases where arresters do not have as favorable characteristics as have been considered herein, or where conditions are unusually severe, the margins will be still smaller or even nonexistent.

**Table III. Analysis of Arrester Protection**

| Basic Insulation | | Short Time | | | | Long Time | |
|---|---|---|---|---|---|---|---|
| Voltage Class (Kv) | Level (Crest Kv) | Arrester Rating (RMS Kv) | Arrester Breakdown Incl. Toler. (Crest Kv) | Circuit Gradient at 1 Kv/Ft | Selectivity Margin† (Kv) | Arrester IZ Drop Incl. Toler. (Crest Kv) | Selectivity Margin† (Kv) |
| **Line Type—Close Coupled Installation** | | | | | | | |
| 2.5 | 53 | 3 | 21 | 4 | 28 | 20 | 33 |
| 5.0 | 63 | 6 | 44 | 4 | 15 | 34 | 29 |
| 8.66 | 80 | 9 | 61 | 5 | 14 | 49 | 31 |
| | | 12 | 73 | 6 | 21* | 63 | 37* |
| 15 | 100 | 15 | 83 | 6 | 11 | 74 | 26 |
| | | 20 | 88 | 7 | 55* | 87 | 63* |
| 25 | 150 | 25 | 110 | 8 | 32 | 107 | 43 |
| | | 30 | 127 | 9 | 54* | 126 | 64* |
| 34.5 | 190 | 37 | 154 | 9 | 27 | 157 | 33 |
| 46 | 250 | 50 | 198 | 11 | 41 | 210 | 40 |
| | | 60 | 237 | 13 | 110* | 252 | 108* |
| 69 | 360 | 73 | 297 | 15 | 48 | 304 | 56 |
| **Line Type—Long Coupled Installation** | | | | | | | |
| 2.5 | 53 | 3 | 21 | 15 | 17 | 20 | 33 |
| 5.0 | 63 | 6 | 44 | 15 | 4 | 34 | 29 |
| 8.66 | 80 | 9 | 61 | 17 | 2 | 49 | 31 |
| | | 12 | 73 | 18 | 9* | 63 | 37* |
| 15 | 100 | 15 | 83 | 21 | —3 | 74 | 26 |
| | | 20 | 88 | 23 | 39* | 87 | 63* |
| 25 | 150 | 25 | 110 | 26 | 14 | 107 | 43 |
| | | 30 | 127 | 28 | 35* | 126 | 64* |
| 34.5 | 190 | 37 | 154 | 32 | 4 | 157 | 33 |
| 46 | 250 | 50 | 198 | 38 | 14 | 210 | 40 |
| **Station Type—Long Coupled Installation** | | | | | | | |
| 2.5 | 53 | 3 | 15 | 20 | 18 | 17 | 36 |
| 5.0 | 63 | 6 | 25 | 20 | 18 | 27 | 36 |
| 8.66 | 80 | 9 | 38 | 24 | 18 | 39 | 41 |
| | | 12 | 43 | 26 | 31* | 58 | 42* |
| 15 | 100 | 15 | 54 | 29 | 17 | 71 | 29 |
| | | 20 | 74 | 31 | 45* | 84 | 66* |
| 25 | 150 | 25 | 89 | 34 | 27 | 110 | 40 |
| | | 30 | 105 | 37 | 48* | 138 | 52* |
| 34.5 | 190 | 37 | 131 | 42 | 17 | 163 | 27 |
| 46 | 250 | 50 | 179 | 49 | 22 | 215 | 35 |
| | | 60 | 215 | 55 | 80* | 268 | 92* |
| 69 | 360 | 73 | 263 | 62 | 35 | 320 | 40 |
| 92 | 470 | 97 | 347 | 78 | 45 | 425 | 45 |
| 115 | 570 | 121 | 430 | 90 | 50 | 530 | 40 |
| 138 | 680 | 145 | 515 | 100 | 65 | 635 | 45 |
| 161 | 790 | 169 | 600 | 115 | 75 | 740 | 50 |
| 196 | 950 | 204 | 714 | 130 | 106 | 900 | 50 |
| 230 | 1,100 | 242 | 860 | 150 | 90 | 1,050 | 50 |

† Basic level minus (arrester performance + tolerance, etc.)
* Margin obtained on grounded neutral system where arrester voltage rating is below basic insulation level classification voltage.

## Conclusions

Insulation co-ordination requires a study of the entire surge protective scheme and, among others, the following items should be considered.

(*a*) Lightning arresters of suitable characteristics connected metallicly and as closely as possible to the equipment to be protected.

(*b*) Protective gaps having suitable flashover voltage characteristics and located on the line side of oil circuit breakers connected to overhead lines. Gaps should not be mounted directly on transformer or breaker bushings.

(*c*) Ground wires properly installed on overhead lines and extending an adequate distance out from the station.

This study of the co-ordination of insulation indicated that insulation levels for various operating voltages could be assigned, depending upon the class of service, the performance of the surge protective equipment utilized, and the economics of the situation. This has been substantiated by years of operating experience with apparatus installed in stations wherein the insulation was designed in accordance with these principles.

Furthermore, it may be concluded that:

(*a*) Full rated lightning arresters which have suitable performance characteristics and which are properly located will provide protection for the basic insulation levels[5] listed in table III (except the 15-kv level) down to extremely short time intervals, except for some direct strokes or unusually severe conditions.

(*b*) Lightning arresters of less than full voltage rating can be utilized on systems having the neutral effectively grounded and will give a greater margin of protection than will full rated arresters. In such installations, apparatus having impulse insulation strength levels one step below the basic level will be protected if the arresters have suitable characteristics.

(*c*) The impulse insulation strengths of electrical apparatus in the various voltage classifications should be equal to or greater than the corresponding basic insulation levels.

(*d*) The alternating voltage dielectric tests for particular conditions should be in conformity with the operating requirements and the insulation level selected. Under particularly favorable operating conditions, it seems reasonable that the alternating voltage dielectric tests may be reduced below present levels.

## References


1. Overvoltages on Transmission Lines, Report No. 30, volume 4, Engineering Reports of the Joint Subcommittee on D. & R., EEI and Bell System, 1936.

2. Distribution Lightning Arrester Performance Data. Report by AIEE lightning arrester subcommittee; Electrical Engineering, volume 56, May 1937, pages 576–7.

3. Application of Spill Gaps and the Selection of Insulation Levels, H. L. Melvin and R. E. Pierce. Elsewhere in this issue.

4. Design of Ground Wires for Direct Stroke Protection, L. V. Bewley. *Electrical World*, March 17, 1934, page 397.

5. Basic Impulse Insulation Levels. Report of EEI-NEMA Joint Committee on System Insulation Co-ordination, elsewhere in this issue.

6. Proposed Transformer Standards. Report of AIEE transformer subcommittee, Electrical Engineering, January 1937, page 32.

7. Insulation Strength of Transformers, J. E. Clem and A. C. Monteith. Elsewhere in this issue.

8. Symmetrical Components (a book), C. F. Wagner and R. D. Evans. McGraw-Hill Book Company.

9. Lightning Currents Measured, H. W. Collins. *Electrical World*, May 12, 1934, page 688.

10. Discharge Currents in Distribution Arresters, K. B. McEachron and W. A. McMorris. AIEE Transactions, 1935, page 1395.

# Surge Protection of Distribution Systems

By J. K. HODNETTE
MEMBER AIEE

L. R. LUDWIG
ASSOCIATE AIEE

## Synopsis

A quantitative investigation of the surge protective requirements of distribution systems and the power frequency voltage requirements of protectors for these systems, has been made which leads to the conclusions that:

1. The surge current discharge capacity of protectors should be 100,000 amperes to prevent damage from lightning. In general, 50,000 amperes capacity will give satisfactory results.

2. The surge voltage breakdown characteristics should be similar in shape and lower in value than the transformer insulation.

3. Field experience, as well as laboratory tests, have proved that a high degree of protection is obtained with a ratio of protective device initial discharge voltage to normal frequency voltage of 9 to 1 in voltage classes up to 13.8 kv, compared to the present conventional arrester rates up to 3.5 to 1.

4. Testing of protective devices under conditions more nearly representative of their service requirements should be considered.

## I. Function and Operation of Surge Protective Apparatus

THE MENACE of lightning to electrical power lines and apparatus is the high surge voltage produced on them which breaks down insulation and renders the line unfit for service. Following such breakdowns, current will flow from the line to ground in order to discharge the energy induced in the line by the lightning stroke. This current may reach extremely high values, and since an arc is usually associated with its conduction to ground, burning and physical destruction may be severe. Finally, large magnetic forces are caused which may damage lines and associated apparatus.

The highly concentrated energy discharge associated with the lightning stroke may be transmitted to the power line in either of 2 ways. First, the lightning discharge may terminate directly on a line conductor, in which case the entire current of the lightning stroke must pass through the line and associated apparatus to ground. This is called a direct stroke. Second, if lightning strikes in the vicinity of a power line, the electrostatic field is raised to such a high value that a considerable overvoltage is induced in it.[1,8] Such surges are called induced surges or indirect strokes. As a result of either direct or indirect strokes, the surge on the line will travel along it in both directions with very high velocity. The wave shape of the surge will change, however, and the traveling wave will be attenuated, so that in the course of even a short distance, the overvoltage will be considerably smaller and the length of the wave considerably greater than at the point where the surge originated.

Protective apparatus connected to power lines for the purposes of minimizing lightning damage must provide a short and direct path to ground in the event of a surge, so that the induced voltage on the line will be held to a value lower than its insulation level. The simplest means of protecting the line and connected apparatus is to suddenly ground it in the event of a lightning discharge. A spark gap is the simplest form of device which can be used for this purpose. The gap will be broken down by the overvoltage introduced on the line and will very quickly pass sufficient current so that the voltage on the insulation will be limited to a small value.

This simple expedient is not ideal, however, since the voltage at which the gap will be broken down increases with increasing rates of voltage rise, and consequently the protection provided is not uniformly good. The volt-time characteristics of such a device are shown in figure 2, curve *D*. Furthermore, the breakdown voltage of a simple gap is erratic and not subject to close control.

A simple gap also has the very great disadvantage that after the lightning phenomenon is over, the line is left grounded. This means that short-circuit current will flow in most cases, and circuit breakers must be opened in order to clear the gap. Consequently, there is a line outage. It becomes then a required characteristic of the lightning protective device that it automatically opens the established circuit between line and ground after complete discharge of the lightning stroke energy.

To accomplish this result it is essential that the simple gap be fundamentally modified. There are 2 known ways of making lightning protectors self-clearing. One principle is to connect a valve element in series with a gap from line to ground. This valve element is so constructed that the impedance drop across it is substantially constant and somewhat greater than the crest of the normal line to ground power voltage. The lightning surge voltage will then be limited to this impedance drop and the "valve" together with its series gap will pass current sufficiently freely to so limit the voltage. After the surge energy of the lightning stroke is discharged only a small current will pass through the valve due to the high impedance which is reached as the surge current decreases. Since it has been impossible to construct a theoretically perfect valve element, the series gap has been introduced to serve the dual purpose of "interrupting" the small residual current which remains after the surge discharge and of isolating the valve from power voltage under normal conditions.

A paper recommended for publication by the AIEE committee on protective devices. Manuscript submitted March 30, 1937; released for publication April 30, 1937.

J. K. HODNETTE is transformer engineer with Westinghouse Electric & Manufacturing Company at Sharon, Pa.; L. R. LUDWIG is division manager for the same company at East Pittsburgh, Pa.

1. For all numbered references see list at end of paper.

The second principle is to enclose the gap in walls of fiber which evolve gas under the action of an arc so that high interrupting capacity is obtained. In this device under some conditions a larger power follow current may flow just after the surge discharge, but it is interrupted at the first current zero. A series resistor is used to limit the magnitude of this power current.

Qualitatively, the common requirements of a satisfactory lightning protective device are:

1. The device must be capable of passing without damage any lightning current to which it is subjected.

2. Its voltage breakdown characteristics should be as nearly linear with time as possible, and under all conditions lower than the apparatus which it is desired to protect.

3. Its impedance drop when passing such currents should be well below the insulation breakdown level of the apparatus to be protected.

4. After passing surge currents, the device must be capable of cutting off any flow of power current even with full power frequency voltage across it.

5. In order to prevent undue operation, the power frequency voltage required to "breakdown" the protective device should be substantially above the normally impressed voltage.

These requirements will be expressed quantitatively in the following sections.

## II. Surge Current Requirements of Protective Devices

For a number of years, engineers have been collecting quantitative data on the nature of lightning strokes—their magnitude, duration, polarity, probability of occurrence, etc., Measurements on transmission lines, distribution lines, and general field measurements have yielded valuable information on this subject. Direct and indirect measurements have been made. The latter have as their basis some physical effects such as mechanical forces, fusion effects, magnetic effects, etc., which are related to or calibrated by laboratory measurements. Indirect measurements have yielded much data on the magnitude and polarity of surge currents. More direct measurements are required to ascertain the shape and duration of surge currents and the nature of repetitive strokes.

The data available indicate the following:[1]

1. The most severe strokes from the standpoint of rate of voltage rise and magnitude of surge current are uni-directional single strokes negative in polarity.

2. Approximately 95 per cent of lightning strokes measured on transmission lines are negative in polarity.

3. Approximately 20 per cent of lightning strokes measured are repetitive.

4. The number of individual discharges in a repetitive stroke ranges from 2 to 10, or more, with the average number 3 to 4.

5. The total time duration of repetitive strokes is from a few hundred microseconds to one or more seconds with the impulses spaced about 0.03 seconds or more.

6. The rate of voltage rise of direct strokes is probably 1,000 to 3,000 kv per microsecond.

7. Measurements indicate a probable maximum surge current of about 200,000 amperes in rare cases.

8. The duration of individual surges varies up to 50 to 100 microseconds maximum with the average probably not over 25 microseconds.

Some of the data available are summarized in figure 1 for comparison. These data represent different methods of measurement. Curve *A* is determined from the fusion effect of lightning currents on metal electrodes of deion gaps and represents data on 4,000 transformer years.[2] From this curve, it appears that from $^1/_2$ to 1 per cent of transformers in suburban and rural areas are subjected to surge currents of 10,000 amperes or higher, and approximately $^1/_4$ per cent are subjected to surge currents of 50,000 amperes or higher.

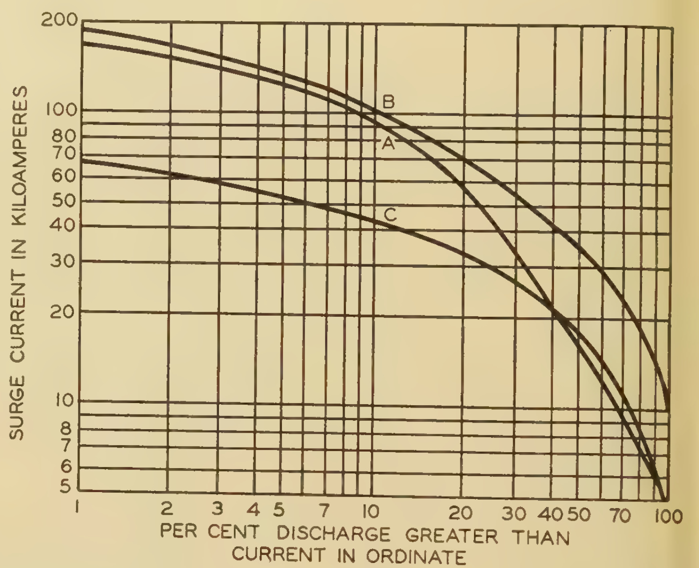



**Figure 1. Magnitude of lightning currents recorded by different methods of measurement**

*A*—Lightning currents at suburban or rural distribution transformers as indicated by fusion effects. 4,000 transformer years[2]

*B*—Lightning currents computed in tower legs on surge-crest ammeter. 911 tower years[3]

*C*—Lightning currents in towers above 5,000 amperes—surge-crest ammeter. 911 tower years[3]

Curve *B* of the same figure, shows the surge current in transmission towers above 5,000 amperes. These measurements represent 911 station years and 235 records in excess of 5,000 amperes were obtained. They indicate 19 per cent per year in excess of 10,000 amperes and $1^1/_2$ per cent per year in excess of 50,000 amperes.

Curve *C* is the computed currents in tower legs.[3] They are based on 911 tower years and 113 measurements, all of which are in excess of 10,000 amperes or a probability of $12^1/_2$ per cent per year at the particular location. The probability of currents of 50,000 amperes and higher as indicated by this curve, is 3.7 per cent.

Measurements by another method were made by H. W. Collins.[4] Out of approximately 500 measurements, in excess of one per cent were above 10,000 amperes with the maximum measured 20,000 amperes.

Additional valuable data on distribution lines has been contributed by McEachron and Halperin[5] on the probability of surge currents in shielded urban areas and by McEachron and McMorris[6] on more exposed lines. These data indicate that the probability of surge currents in excess of 10,000 to 20,000 amperes in shielded urban areas is very remote indeed. In rural areas, however, 1 per cent of the surges were found to exceed 15,000 amperes.

A summary of the data indicates that at least 1 per cent of the surge discharges will exceed 10,000 amperes and an appreciable fraction of 1 per cent will reach 50,000 amperes. An efficient and satisfactory protective device should be capable of handling surge currents of this order of magnitude.[7]

In analyzing data of this nature, it is necessary to take into account the natural difficulties of measurements. Due to the numerous points of low insulation level of distribution lines, diversion of current through multiple paths takes place easily, so that measurement at any one point may not be indicative of the maximum currents to be expected. From the physical concept of the problem, it would be expected that the maximum currents would be of the same order as those obtained on high voltage transmission lines, particularly in exposed circuits.

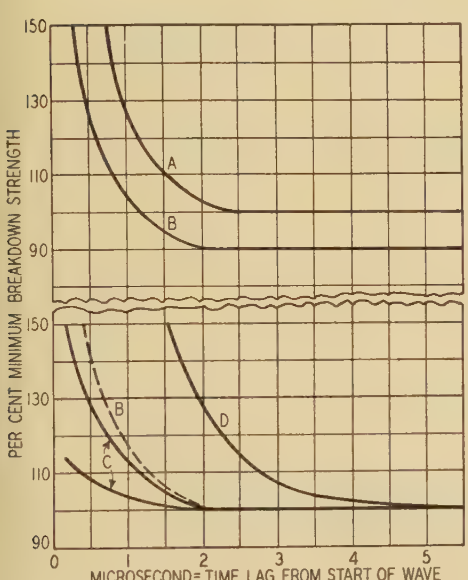



**Figure 2. Comparison of impulse characteristics of distribution transformer insulation and protective devices**

*A*—Breakdown characteristics of distribution transformer insulation

*B*—Probable voltage and time curve at which deterioration begins

*C*—Flashover characteristics of deion gaps and arrester gaps compared with *A* and *B*

*D*—Approximate shape of bushing and rod-gap flashover curves (13.8 kv class) compared with *A* and *B*

The probability of surge current of a given magnitude occurring at any particular location on a distribution system decreases rapidly with increasing current. Some potential exists by induction at practically all locations every time there is a lightning discharge in the vicinity. The nearer the discharge to the line, the higher the potential on the line will be. Due to the reduced insulation level at transformer locations and other points along the line, induced currents exceeding 2,000 amperes would not be expected. With the advancement in the art of surge protection, transformer insulation and protective devices, currents of this amplitude are of no serious consequence. The serious problem of protecting distribution systems, as well as high-voltage transmission systems, is to deal with direct and near direct strokes. In distribution systems, this problem is complicated by the fact that most distribution lines are carried on wooden poles having a high insulation value to earth. Also, the resistance of the earth at the poles may be quite high. This combination of factors makes it possible for surge currents of high magnitude to travel long distances along distribution lines and be diverted to earth through the low resistance path of the transformer secondary services. This means that lightning does not have to strike very near transformer locations for them to be subjected to high surge current. With the rapid extension of distribution systems into exposed rural areas, adequate surge protection afforded by protective devices capable of handling severe lightning stroke currents is paramount.

The time duration of surge discharges through lightning protectors has not been as completely measured as the current magnitudes. Available data indicate, however, that a lightning stroke of 50,000 amperes will generally have a time duration of 25 microseconds at least. Consequently, time values of this order of magnitude should be considered in judging the surge current handling ability of protective devices.

The fact that many lightning strokes are repetitive argues that if the surge current capacity of a lightning protector is to be defined in terms of a single stroke, some allowance must be made for the cumulative dissipation of energy associated with multiple strokes. Consequently, there is additional reason for placing the minimum acceptable surge current capacity at a high value.

## III. Voltage Protective Requirements

Adequate protection of distribution transformers and other equipment on distribution lines necessitates that the protective device limit the voltage that can exist on the insulation of the equipment to a value that will not damage any part of it. In considering the voltages existing on a distribution system, one has to take into account the high density of transformer locations and other points of reduced insulation. It is impossible, therefore, for voltages of very high magnitudes to be propagated on distribution lines as traveling waves. In general, impulses of this character are harmlessly drained off to ground by protective devices even under unfavorable grounding conditions. Impulses of a more dangerous or damaging character appear as a rapidly rising voltage suddenly reduced by a flashover of the line or a discharging of the protective device, followed by a building up of current through the circuit so formed to earth. This current produces a voltage drop by virtue of the impedance

of the protective device itself and of the circuit in which it is connected. It is imperative that the impedance of this circuit be sufficiently low so that the voltage impressed on the apparatus under the most severe conditions of surge discharge will not damage the insulation of the apparatus. Both the impedance of the protective device and the surge impedance of leads and connections must be small and, consequently, it is necessary that the connections be made as short as possible. To illustrate this fact, it is possible to build up voltages in excess of 10,000 volts per linear foot in straight conductors in the laboratory. All beneficial effects of the protective device can be nullified by long connections.

Distribution transformers are the major apparatus connected to distribution systems. The quality and characteristics of the insulation is an important factor in the successful operation of the distribution system. The normal frequency voltage strength must be sufficiently high to prevent damage from normal overvoltages, arcing grounds, etc., and to prevent corona and radio interference. This is insured by acceptance tests specified by the AIEE. Knowledge of the insulation strength of transformers to impulse voltages is necessary to intelligently co-ordinate and successfully apply protective devices.

A careful study of the impulse characteristics of distribution transformer insulation has been made. Due to the many factors influencing the ultimate impulse strength of transformer insulation, quantitative data can best be analyzed on the basis of average results or guaranteed values.

There exists a fairly definite ratio of the impulse strength of well balanced transformer insulation to its normal frequency strength. This ratio has been expressed numerically as 2.2, based on the 60-cycle crest value of the insulation breakdown strength. Applying this factor to the acceptance test voltages gives an indication of the minimum impulse strength built into transformers by the manufacturer. These values for low voltage distribution transformers are given in table I. In this class of apparatus the manufacturer maintains a much higher margin of safety to minimize mechanical defects and to insure reliable service than in higher voltage apparatus. While this margin cannot be definitely utilized, it nevertheless aids in preventing damage from lightning.

The volt-time characteristics of the insulation and protective devices is shown in figure 2. Curve $A$ shows the characteristics of transformer insulation for a $1^1/_2$x40 microsecond wave. The minimum or full-wave impulse strength is represented as 100 per cent and as a function of time in microseconds from the start of the voltage wave. The shape of this curve was determined by the average of a large number of tests to failure of actual distribution transformers.

Curve $B$ of figure 2 shows the probable limits of voltage and time below which deterioration of the insulation is not expected to occur. The shape and values of this curve are established by applying repeated impulses of a given voltage and time duration to a transformer and noting whether or not deterioration begins. In applying this curve to a particular transformer, it is necessary to take into account the natural variation or spread in impulse strength of transformers of the same voltage class and design. It is applicable to the figures in table I, directly without encroaching upon the manufacturer's margin of safety.

On the same figure, curve $C$, showing the volt-time characteristics of deion gaps and lightning arresters, is given. Note that these curves are lower and flatter than curve $B$. Also, the approximate shape of the voltage-time flashover of bushings and standard rod gaps for 6,900–13,800 volt class transformers is shown as curve $D$. While these 2 curves are not exactly of the same shape, they have the same general characteristics. Note that the bushing and rod gap curves are higher than the curve of probable insulation deterioration, as well as the insulation breakdown strength. For lower voltage classes, both the rod gap and bushing flashover characteristics are flatter due to their more uniform dielectric fields. It is necessary, however, to resort to considerably shorter gaps than the recommended co-ordinating gaps before the flashover curves are similar in shape to the insulation breakdown curve.

These curves illustrate the desirability of a surge

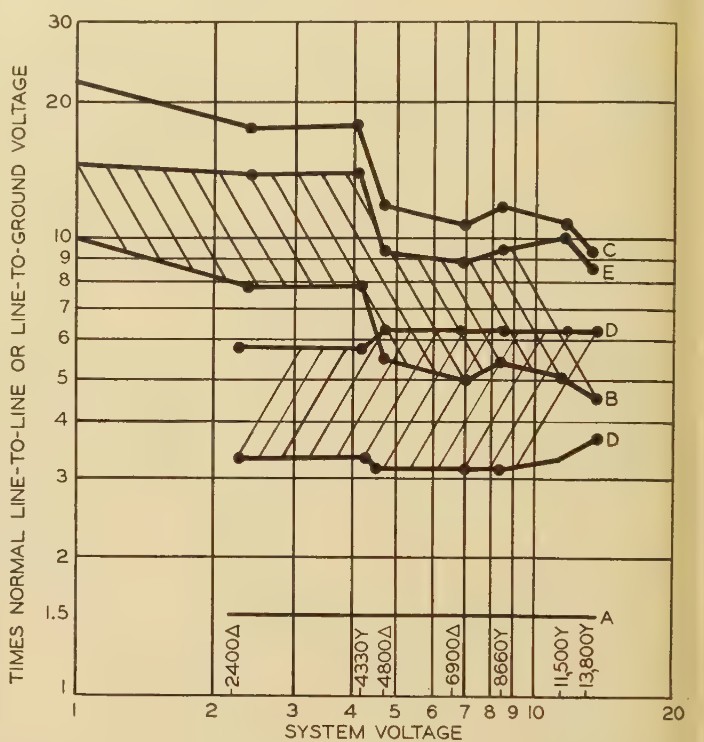



**Figure 3. Comparison between protective devices and transformer test levels**

$A$—Minimum 60-cycle voltage requirements of protectors

$B$—One minute dielectric acceptance test

$C$—Minimum impulse strength based on $B$

$D$—Valve type lightning arrester breakdown voltage level

$E$—Deion gap arrester breakdown voltage level

protective device having voltage discharge characteristics similar in shape to the insulation characteristics of the transformer, and also the fact that standard bushings and rod gaps do not have this.

The history of past development shows that protective-device engineers have constantly endeavored to design and produce apparatus which would be more reliable and which would have a lower ratio between discharge voltage and normal frequency line voltage. These 2 requirements have not been entirely compatible and have been accentuated by code requirements. With the advancement in the knowledge of the characteristics of natural lightning and with it the theory of surge protection, the codes have been modified to remove these restrictions. Transformer engineers have kept pace by obtaining knowledge of transformer insulation characteristics and limitations. The protective-device engineer should have a free hand to design apparatus suitable for the service required of it and unhampered by past traditions. This means simply proper co-ordination of transformer insulation levels and protective-device discharge voltage. As indicated by table I, it is satisfactory to design distribution surge protective equipment for much higher discharge voltages than would have been considered practical several years ago.

## IV. Normal Frequency Requirements of Lightning Protectors

The desire to reduce the surge level of lightning protectors to a low value results in designing these devices so that their normal voltage cutoff is reasonably close to the applied power voltage. If this procedure is carried too far, the protector itself is endangered and it becomes a hazard to the power system. Consequently, at times there have been failures of these devices which were not associated with the discharge of lightning energy. It is, therefore, necessary to examine the power voltage conditions of the circuit to which the lightning protectors are to be applied, in order properly to design and use this type of equipment.

Generally, protectors are applied to 3-phase power systems. These systems may be operated with the neutral solidly grounded or free from ground. In either case, the normal line to ground voltage will be the line-to-line voltage divided by 1.73. In the event of a fault from one line to ground, however, the performance of the 2 classes of systems is quite different. The solidly grounded neutral system will, under theoretically ideal conditions, prevent the line-to-ground voltage during fault conditions, from rising at all. Actually this voltage will increase to a value of approximately 120 per cent normal line to ground voltage in average cases. If the neutral is not grounded, the full line-to-line voltage will appear from line to ground in the event of a ground fault on one conductor. Consequently, it is essential that the protective device be capable of interrupting the flow of power current after surge discharge with a voltage applied which will be at least 120 per cent of the normal line to ground voltage if the neutral is grounded, and which will be at least 1.73 times line to ground voltage if the neutral is ungrounded.

Grounded neutral systems are subject to considerable variation depending on the magnitude of the ground impedance. While the average overvoltage from line to ground in the event of a fault may be only 120 per cent, lightning protectors must operate satisfactorily on systems of high ground impedance. Furthermore, protectors may be located at a considerable distance from the point of actual grounding and a line to ground fault near the protector location effectively increases the ground impedance so far as voltage across the protector is concerned. It is very difficult to determine the maximum per cent of line-to-line voltage which the protector should withstand, but experience indicates that the value should be 80 per cent for solidly grounded neutral systems. In other words, the line-to-ground voltage will rarely exceed 140 per cent of its normal value.

Systems in the distribution voltage class are generally supplied with power through step-down transformers from higher voltage systems. In case lightning strikes the high-voltage system, surges of considerable magnitude may cause a flashover to ground and power current may flow through ground for several cycles. If the neutral points of the 2 systems are connected together to a common ground of comparatively high resistance, this flow of power current in the high-voltage system may introduce considerable overvoltage of power frequency in the low-voltage system. Direct flashover from the high to the low-voltage system during the surge is also a possible cause of high dynamic voltages on the low-voltage system. Obviously, the greater the difference between the normal voltage of 2 connected systems, the greater is the possibility of excessive power-frequency voltages introduced into the low-voltage network as a result of fault conditions. Consequently, it is good practice to build lightning protective devices at the lower voltages with a greater factor of safety or difference between maximum permissible line-to-ground voltage and normal line-to-ground voltage, than is the case with lightning protectors of the high-voltage class.

Generally low-voltage lightning protectors are applied with less care than high-voltage devices. Often it is not possible to employ a theoretically ideal rating because low manufacturing costs preclude the availability of a wide range of voltage classes. These facts again introduce the requirement that the voltage tolerance of distribution lightning protectors should be comparatively great.

Another factor which at times influences the required voltage cutoff characteristics of lightning protectors, is the presence of harmonics in the supply voltage, particularly during fault conditions. Normally the applied voltage is sufficiently sinusoidal so that the crest value bears the normal relation to the meter readings. During faults, however, saturation of transformer iron may introduce harmonic voltages. The nature of the main power source must also be considered, since waterwheel generators without damper windings are subject to producing high harmonic overvoltages during line-to-line short circuits. It is furthermore possible that in certain

cases various lines and connected apparatus will be resonant to these harmonics, and cases have been experienced where very high harmonic overvoltages were present during fault conditions from line to ground.

Surges resulting from switch operations on the lines may at times prove hazardous to lightning protector devices. Switching surges differ from lightning surges principally in 2 respects. First, the magnitude of overvoltage is much lower in the case of switching surges and major insulation is not endangered. Second, the duration of the switching surge may be much longer than the lightning surge, however, and the energy which must be dissipated in a protective device may be greater for the switching surge than for the lightning surge. Consequently, the lightning protector must be built sturdily enough so that it will handle any currents passing through it as the result of normal switching operations.

As lightning protectors are generally constructed, a certain minimum voltage must be impressed across them before they begin to pass appreciable current. In other words, these devices exhibit definite breakdown characteristics. Generally, the breakdown voltage of protectors is considerably higher than their cutoff voltage. This is fundamental in the design of these devices, because the isolating means is generally a gap of some form and it is impossible to design a gap so that it will interrupt current up to the voltage necessary to cause a breakdown. Furthermore, it is very desirable to set the breakdown voltage of the devices considerably above normally applied voltages, and in many cases higher than the normal switching surges. In this way unnecessary operations of the protective device are prevented.

In the distribution voltage class it has been general practice to have the breakdown voltage at least 1.5 times the maximum permissible voltage or cutoff value of the device. This figure is low for the best obtainable performance. The breakdown voltage at normal power frequency may easily be 2 to several times the cutoff voltage without impairing the surge protective characteristics, and if the designs are made in this way much greater safety of the protective device itself is obtained.

## V. Voltage Levels of Protective Devices

The 2 preceding sections define the upper limits of discharge voltage of protective devices, and the lower limits of power frequency cutoff and breakdown voltage. In figure 3 the minimum insulation impulse strength has been plotted (curve $C$) for the different distribution voltage classes. The basic data for this curve are taken from table I. Also the minimum acceptable power frequency breakdown voltage has been plotted in figure 3 (curve $A$). The difference between these 2 curves is a broad band into which the characteristics of the protective device must be fitted. Since the 60-cycle and surge discharge voltage of protective devices is different, or in other words since their impulse ratio is greater than unity, 2 curves must also be plotted for the protective device. These 2 curves again form a band which is much narrower than the band of required performance. The difference represents the total margin of safety of the protective device over service requirements. This total margin can be divided by design between margin over 60-cycle minimum requirements and margin under surge requirements. On account of the relatively great total margin, there is considerable choice in the design of the lightning protector.

**Table I. Comparison of Guaranteed Normal Frequency and Impulse Strength of Distribution Transformers Based on AIEE Standards and Recommendations**

| | | Expected Minimum Impulse Strength Based on | | | |
|---|---|---|---|---|---|
| Voltage Class (RMS Kv) | Dielectric Test (RMS Kv) | Dielectric Test (Crest Kv)* | Test Gap Inches | Test Gap (Crest Kv)* | Bushing Flashover† (Crest) |
| 1.0 | 10 | 31 | 0.8 | 32 | 37 |
| 2.4– 4.3 | 19 | 59 | 2.2 | 59 | 68 |
| 4.8– 8.7 | 26 | 81 | 3.3 | 81 | 87 |
| 6.9–13.8 | 34 | 106 | 4.5 | 102 | 107 |

* Minimum flashover or full wave for 1½x40-microsecond positive waves.
† Maximum voltage applied in making impulse tests which flashes over bushing or equivalent gap. See recommendations of transformer subcommittee on impulse testing.

In figure 3 curves are also plotted showing the minimum 60-cycle and maximum surge characteristics of valve arresters (curve $D$). Arresters have been widely applied to protect insulation of varying and unknown surge strength, and consequently, their characteristics have been designed to be comparatively low. Deion protectors, on the other hand, have generally been designed as an integral part of distribution transformers of known insulation strength. Furthermore, the transformers are tested on 60 cycles with the deion protector connected, and it is consequently necessary to maintain the 60-cycle breakdown of the protector higher than the test voltage applied to the transformer (curve $B$). For these reasons, the deion protectors have surge characteristics considerably higher (curve $E$) than those of valve arresters. Field service records prove conclusively that both devices provide adequate protection to the transformers.

## References


1. General reference bibliography, Electrical Engineering, August 1935, page 842. Also, discussions and references, Electrical Engineering, April 1936, pages 393–6.

2. Lightning Currents in Field and Laboratory, P. L. Bellaschi. Electrical Engineering, August 1935, page 837.

3. Lightning Currents in 132-Kv Lines, Philip Sporn and I. W. Gross. Electrical Engineering, February 1937, page 245.

4. Lightning Currents Measured, H. W. Collins. *Electrical World*, May 12, 1934, page 688.

5. Lightning Measured on 4 Kv Overhead Circuits, Herman Halperin and K. B. McEachron. Electrical Engineering, January 1934, page 33.

6. Discharge Currents in Distribution Arresters, K. B. McEachron and W. A. McMorris. Electrical Engineering, December 1935, page 1395.

7. Surge Currents in Protective Devices, A. M. Opsahl. Electrical Engineering, February 1935, page 200.

8. Direct Strokes Not Induced Surges Chief Cause of High Voltage Line Flashover, C. L. Fortescue. *Electric Journal*, August 1930, page 459.

# Application of Spill Gaps and Selection of Insulation Levels

By H. L. MELVIN
FELLOW AIEE

R. E. PIERCE
MEMBER AIEE

## Synopsis

This paper presents, from the viewpoint of the engineer who plans and operates electric power systems, the application logic or theory and the performance results with various forms of spill gaps, for the protection of circuits and equipment from lightning, and the selection of insulation levels co-ordinated with this type of protection.

The performance results are largely confined to transmission voltages, although the same general principles and logic apply over the entire transmission and distribution operating voltage range.

## Background

As a BACKGROUND of scientific research, service observation, and engineering experimentation the industry has available the results to date of study in 4 fields, concerned with protection of circuits, equipment, and service against lightning:

1. Field research of natural lightning, also laboratory research, having to do with the nature and occurrence of lightning[1,2,3]

2. The volt-time characteristics of insulators and insulating materials under impulse and normal frequency voltages[4,5]

3. The performance characteristics of gaps and lightning arresters in commercial use[4,6]

4. Analyses of observed operating performance of electric transmission and distribution systems with particular reference to protection from lightning[2,7]

In none of the above 4 fields of investigation and experience can it yet be said that the results or knowledge are so complete that unqualified conclusions can be drawn with respect to each of the pertinent factors in the problem. Nevertheless, enough has been learned that it has been possible to formulate tentative insulation and protection policies and to secure from actual experience a reasonably conclusive check as to their soundness.

## General Aspects of Lightning Protection

As in most transmission and distribution problems the best solution to the protection problem is judged in terms of both performance and cost.

Protection from lightning has 2 primary aspects:

1. Protection of equipment against damage
2. Protection of service against interruptions

Each of these is capable of separate evaluation, and obviously is dependent on such factors as density of load, type of load, and degree of exposure to lightning.

The methods available for accomplishing protection may be broadly divided into the 2 groups of shielding and drainage.

### Shielding

Shielding of circuits and equipment is accomplished either by underground construction, or by the so-called "lightning proof" type of construction. To be effective, the shielding must be capable of withstanding all direct strokes of lightning, except possibly the most severe, without breakover or conduction of the lightning current to the power conductors.

Shielding within the limitations of the specific installation, protects service and equipment. Unfortunately it is economically feasible only in the case of the higher transmission voltages, and on circuits of major importance.

In the lower transmission and distribution range of voltages, overhead circuits are not generally shielded. There are also many situations with the higher transmission voltages, where lightning storms are infrequent or where lines serve large areas having small load densities, where the added investment for shielding disqualifies it from the standpoint of economy.

### Drainage

Drainage is accomplished by providing for relief and limitation of lightning voltages through flashover at preferred locations. This includes the use of:

1. Plain gaps with which no attempt is made to interrupt or seal off power follow current

2. Fused gaps in which the series fuse interrupts the power follow current. These have limitations in application with respect to interrupting ability

3. Lightning arresters which do not permit power follow current. Their effectiveness is limited to their surge current discharge capacities

4. Arc-interrupting gaps, in which the series tube interrupts the power follow current. These tubes have limitations with respect to minimum and maximum interrupting ability, and their application as at present commercially available is confined largely to line insulation protection

## Application of Spill Gaps

The logic underlying the application of spill gaps of any type is:

1. A spill gap provides a definite voltage discharge level with very high capacity for discharging lightning stroke current. The setting may be in terms of inches of air or in terms of voltage and time. The cost of the installation is the very minimum

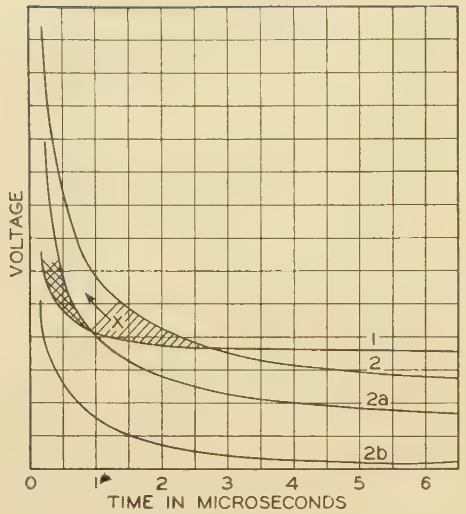
A paper recommended for publication by the AIEE committees on protective devices, power transmission and distribution, and electrical machinery. Manuscript submitted March 29, 1937; released for publication April 27, 1937.

H. L. Melvin and R. E. Pierce are electrical engineers for Ebasco Services, Incorporated, New York, N. Y.

The authors acknowledge the use of much information available both from previously published papers and from reports covering the performance of transmission and distribution systems of operating companies with which the authors are associated. These operating data have made possible the most valuable part of this paper.

1. For all numbered references see list at end of paper.

Figure 1




2. Except for solid or oil insulated equipment, practically all line and substation insulation can be expressed approximately in terms of equivalent inches of air

3. Co-ordinated with line insulators, bushings, switch and bus insulators, spill gaps provide dependable relief from dangerous surge voltages, at preferred locations for flashover, establishing definite levels in terms of inches of air or in terms of voltage and time

The usual application of the different types of spill gaps is:

1. Spill gaps of the extinguishing types, that is, arc-interrupting gaps or fused gaps, installed along a transmission or distribution circuit, are used for 2 purposes:

*a*. To provide a definite margin under the line insulation so that flashovers along the line will occur at the gaps, with interruption of power-follow current, to prevent line outages

*b*. To limit the voltage impressed on the circuit and transmitted to installed equipment

2. Plain spill gaps are installed at substations:

*a*. At the line entrances, with margins under all other insulation levels within the substation

*b*. Within the substation, on the bus or at equipment, with discharge levels somewhat higher than those established at the line entrances, as final or back-up protection against bus flashover or equipment failure

3. Fused spill gaps are installed at substations either at line entrances or on the bus or at equipment in a manner similar to and supplementing plain spill gaps to protect against service interruptions. Their use depends upon the expected frequency of lightning flashovers and the type and importance of the load served.

## Selection of Insulation Levels

### Basic Insulation Levels

During early discussions on insulation co-ordination it was common practice to think of insulation levels in terms of the amount of porcelain insulation or in inches of air (rod gap), in which case a level would not be a level in terms of voltage but would vary with the volt-time breakdown curve of the rod gap or insulators.

More recently, the accepted measure of a basic insulation level is in terms of volts, and is therefore more truly a level, being a constant value of voltage, regardless of the time to breakdown, except that the time is limited to a range in microseconds usually associated with impulse voltages.

Nevertheless, insulation as used, does not have a fixed voltage breakdown strength, and the volt-time breakdown curve of each unit of insulation or piece of apparatus is its own insulation level.

A "basic" insulation level serves no other purpose than as one of a series of standardized voltage bench-marks to which the insulation levels of line and station insulators, bushings, transformers, protective devices, and other equipment may be referred in the process of selecting a proper or desired level of insulation for a particular installation and working out co-ordination.

The minimum practicable basic insulation level that may be established for a given installation must be high enough so that insulation flashovers or failures will not occur from normal frequency overvoltages or from surge voltages originating within the system, such as switching surges.

The adoption of these minimum insulation levels on a system would result in minimum initial investment in line and station equipment insulation. This practice may not be practicable in specific situations, as for example a basic insulation level above the minimum often will be advisable in order to provide (1) equipment levels that will directly withstand or are capable of being protected against incoming traveling lightning voltages, or (2) equipment levels that can be adequately protected against severe nearby direct strokes of lightning.

### Insulation Levels for Equipment

The selection of the insulation levels for the bus and equipment, such as transformers, co-ordinated with a given basic insulation level, must take into account:

1. The relative volt-time characteristics of the other equipment including the protective device

2. The economic margin of protection, taking into consideration the expected severity and frequency of occurrence of lightning surge voltages

3. Margins to provide for variations in insulation strength due to manufacturing tolerances and from deterioration

Insulation research has demonstrated quite definitely that the breakdown of insulating materials under impulse voltages is a function of voltage and time. For fibrous insulations of most equipment the volt-time breakdown curve has the general shape of curve 1, figure 1. The curve is relatively flat except at the very short time intervals.

The impulse flashover characteristics of gaps are found to have the general shape of curves 2, 2*a*, and 2*b*. As compared to the curve for solid insulation, the gap curves are not as flat, voltage values rising sooner as the short time region is approached.

Assuming gaps and insulation as illustrated, gap 2*b* would prevent flashovers of gap 2*a*, and gap 2*a* would protect gap 2. Gap 2 would protect the insulation represented by curve 1 only against impulse voltages rising to flashover of the gap in a time longer than that point on the time scale where the 2 curves cross. Impulse voltages rising to crest or to flashover of the gap in region *X* would damage the insulation represented by curve 1. A greater time range and margin of protection would be secured to the insulation by gap 2*a*, and over the entire time range il-

lustrated, with margin, by gap 2*b*. These are equivalent to providing protection against more severe lightning impulse voltages.

In spite of the large amount of work which has been done investigating actual strokes of lightning, insufficient knowledge and data are available concerning the voltage magnitudes and rate of rise at the point of stroke incidence and the relative probable frequency of occurrence of direct strokes of the greatest severity. For the present at least, reliance must be placed upon the record of operating experience to tell when a satisfactory degree of protection has been achieved.

## Operating Experience With Spill Gaps

For discussing gap settings generally, without necessarily always referring to the associated system operating voltage, figure 2 has been prepared as a convenient reference chart, wherein the commonly accepted 60-cycle flashover values of rod gaps are plotted in terms of the number of times normal phase to neutral voltage, for the range of rated circuit voltages.

### Minimum Permissible Settings

Perhaps the most outstanding result secured from the observation of operating experience with gaps over the past several years is that, even in areas frequented by severe lightning storms, much lower spill-gap settings can be used than were originally considered possible.

For transmission voltages on grounded neutral systems, it generally has been found that gap settings corresponding to approximately 2 times normal (phase - to - neutral voltage) are the lowest possible. That is, gap settings of these magnitudes may be used without an undue number of flashovers, if any, due to switching surges. However, the more generally applied minimum gap settings in the transmission voltage range correspond to approximately 3 times normal voltage to neutral.

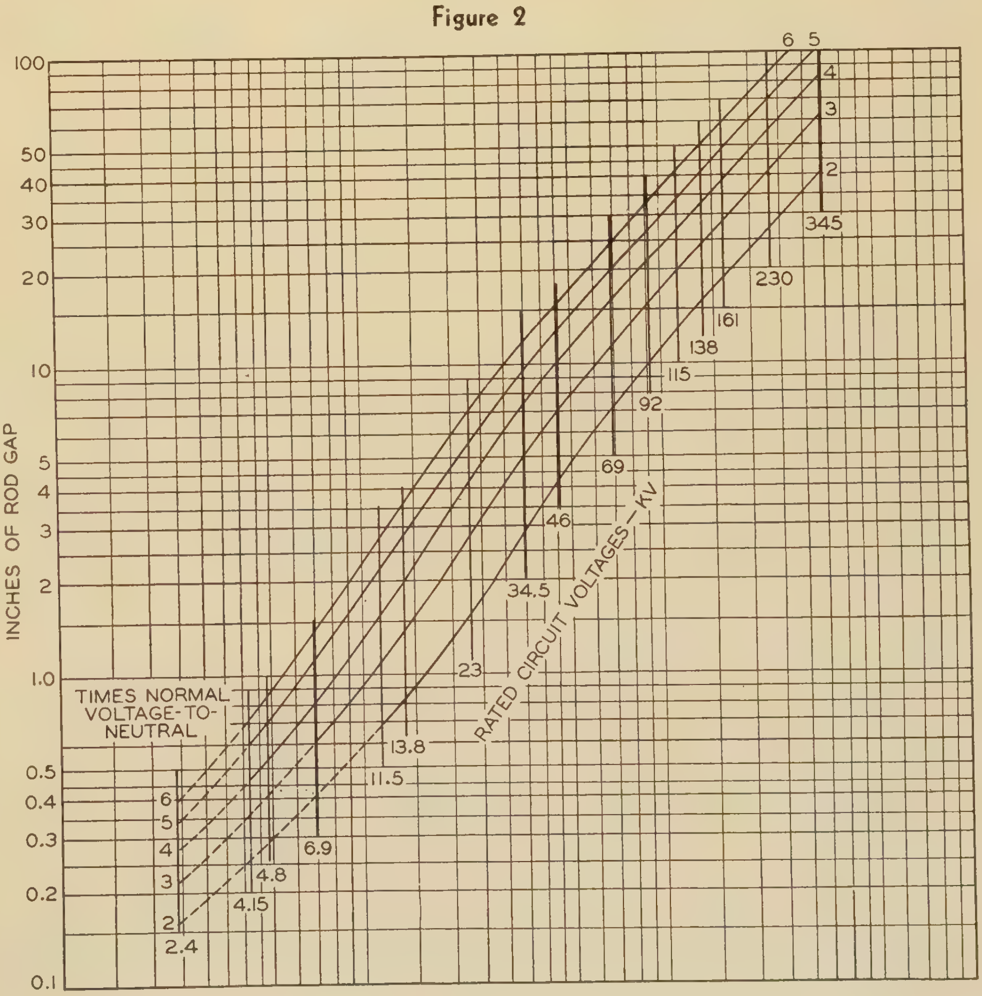
In the distribution voltage range, the minimum gap settings are relatively higher, as they are fixed, not so much by switching surges and overvoltages, as by mechanical and other considerations such as interference from birds, also higher settings are permissible due to the relatively greater prevailing insulation strengths of equipment.

Probably the extreme lower limit of permissible gap settings is typified by operating experience at a substation in Louisiana on the extensive 110-kv grounded-neutral system in the lower Mississippi Valley. This substation is at the end of a 110-mile section of single circuit H-frame line, having very high impulse insulation strength. Following a number of transformer failures, during which time the gap settings were reduced by steps from 31 inches to 18 inches, staged switching tests were made to determine the minimum permissible gap setting. In these tests the gap settings were reduced by steps to 10 inches. With the 10-inch setting during one setup on the system, these gaps flashed over twice during 15 switching operations, although on another system setup 65 switching operations did not cause flashover. The gap settings were increased to 11 inches and did not flash over during 45 switching operations under the same setup which caused flashover with the 10-inch setting.

These tests were made early in 1935 and the gaps have subsequently remained in actual service with the 11-inch setting during 2 lightning seasons. The gaps are of the repeater fused type, mounted directly at the transformer terminals. The setting of 11 inches is equivalent to approximately 1.7 times normal phase-to-neutral voltage.

At another substation on this same 110-kv system, where 11-inch repeater fused gaps were installed in 1936, further tests have definitely indicated that the switching surge caused by the opening of an oil circuit breaker on a

Figure 2



stub line can cause an 11-inch gap to flash over.

Early in 1936, at the first substation, 2 additional sets of repeating fused gaps were installed, with the 11-inch setting. Retaining the original set at the transformers, one new set was installed on the first structure of the incoming 110-kv line, and the other set on a line structure about 2 miles from the substation. During the year 1936, the total number of fused gap operations, on all 3 phases, at the 3 locations, were as follows:

| | Number of Operations of Repeater Fused Gaps |
|---|---|
| At the transformers | 28 |
| At the first line structure | 21 |
| At structure 2 miles away | 20 |

A definite correlation was not determined between fuse-gap operations at the 3 locations or between operations of individual fuse gaps and oil-circuit-breaker openings. There probably were a number of simultaneous operations of gaps. The evidence indicates that if any of the gap flashovers were occasioned by switching surges, they were successfully cleared by operation of the series fuses. During the year the line tripped out a total of 28 times due to lightning flashovers.

### Effect of Gap Settings on Number of Flashovers

Along shielded overhead circuits, the values of voltage induced on the circuit conductors through coupling effects, vary with the severity of the strokes of lightning to the line. The maximum voltage that can appear on the circuit at the point of stroke is limited to the line insulation level.

Along exposed circuits, there is probably less variation in the magnitude of the lightning voltages appearing on the circuits as it seems reasonable to assume that any direct stroke and most side flashes and branch streamers would cause line flashover, regardless of the amount of line insulation. The voltage therefore is determined by and limited to the line insulation flashover level.

In any case the impressed surge voltage at the point of stroke, travels toward the line terminals and appears at substations, after being subjected to the effects of attenuation and reflection, with magnitudes very seldom any greater and usually much less than at the origin.

Experience with both shielded and nonshielded lines in different parts of the country, all exposed to frequent and severe lightning, indicates that with gap settings at substations equivalent to or greater than 3.5 times normal phase-to-neutral voltage, there are relatively few gap operations compared with the number of line tripouts or line flashovers from lightning. There are an increasing number of gap flashovers, as lower and lower settings are used.

The following paragraphs cite typical experience with gap settings ranging from 3.5 down to 1.7 times normal, for transmission voltages. While only limited data are included, experience on these and other situations covers a period of 6 to 10 years.

As an example of experience with gap settings averaging 3.5 times normal for transmission voltages, and somewhat higher for distribution, the following number of stations were protected during 1935 and 1936 by spill gaps in central and eastern Texas. The performance record of these spill gaps during this period is summarized in table I.

| | Number of Substations Protected 1935 | 1936 |
|---|---|---|
| 22 kv and above | 50 | 55 |
| 12.5 kv and below | 44 | 65 |
| On both high and low voltages | 20 | 25 |
| Total number of stations protected on either high or low voltage by spill gaps | 74 | 95 |

In Florida, on a 66-kv system, with line-terminal gaps set at 11 inches (approximately 3.0 times normal), and with line-insulation levels equivalent to 14 inches to 45 inches, of air, experience indicates that gap flashovers at the substations occur with about 4 per cent to 16 per cent of the lightning flashovers on the lines. The lower and higher percentage values are associated with lines of low and high insulation levels, respectively.

At a generating station bus in Arkansas, on the same Mississippi Valley 110-kv system previously mentioned 3 14-inch spill gaps per phase with series fuses (approximately 2.2 times normal) were installed in July 1934. In

**Table I. Spill-Gap Performance in Texas—1935–36**

| Operating Voltage (Kv) | Gap Settings: Inches | Gap Settings: Times Normal* | Number of Individual Phase Gaps in Service: 1935 | 1936 | Number of Individual Gaps Which Did Not Flash Over During the Year: 1935 | 1936 |
|---|---|---|---|---|---|---|
| 132 | 20–36 | 2.5–4.5 | 69 | 69 | 64 | 68 |
| 66 | 12 | 3.1 | 249 | 249 | 245 | 246 |
| 60 | 10–12 | 2.8–3.2 | 153 | 153 | 148 | 149 |
| 33 | 6–8 | 3.5–4.4 | 12 | 15 | 12 | 15 |
| 22 | 5-6** | 4.6–5.2 | 54 | 69 | 53 | 68 |
| 12.5 | 1 3/4–3† | 4.0–5.8 | 282 | 402 | 275 | 395 |
| 7.2 | 1 3/4 | 7.0 | 9 | 15 | 9 | 15 |
| 4.16 | 1/2–3†† | | 27 | 27 | 27 | 26 |
| 2.4 | 1 3/4 | | 18 | 18 | 18 | 18 |
| | | | 873 | 1017 | 851 | 1000 |

* Gap 60-cycle flashover in terms of number of times the normal phase-to-neutral voltage

** In some cases with 1-inch or 2-inch auxiliary gaps in series with main gaps

† In most cases with 1-inch series gaps

†† In most cases with from 1/4-inch to 1-inch series gaps

**Table II. Two-Year Performance of Arc-Interrupting Gaps on 66-Kv Lines in Pennsylvania—1935–36**

| Miles | Structures | Structures With Gaps | | Gap Operations | | Line Tripouts | Cases of Damage to Structures | | Cases of Damage to Gaps | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Number | Per Cent | Structures | Gaps | | 1935 | 1936 | 1935 | 1936 |
| 36.4 | 355 | 91 | 25.6 | 95 | 158 | 11 | 1* | 4* | 0 | 7** |
| 13.8 | 160 | 23 | 14.4 | 54 | 100 | 3 | 2* | 5* | 4 | 19** |
| 17.8 | 175 | 175 | 100 | 149 | 203† | 0 | 0 | 0 | 0 | 0 |
| 13.4 | 130 | 130 | 100 | 175 | 306 | 0 | 0 | 0 | 0 | 0 |

* On unprotected structures
** Primarily loss of targets
† Line not put into service until after close of 1935 lightning season; 65 gap operations occurred on dead line
Note: Each of the four lines are single-circuit H-frame wood construction.

each of the years 1934 and 1935 there were 3 operations of the gaps, and in 1936 there were 4 occasions of gap flashover totaling 8 individual gap operations. All operations were associated with lightning and none caused service interruptions, except for one case in 1935 in which the fuse tube exploded.

At another substation in Arkansas similarly equipped in 1935 with 14-inch fused gaps on the bus, there were in 1936 3 occasions of gap flashover totaling 5 individual gap operations, without interruption to service.

At one of the 110-kv substations in Louisiana previously mentioned, the operating experience throughout the year 1935, with one 3-phase set of 11-inch repeater fused gaps (1.7 times normal) at the transformers, included a number of difficulties due to tube failures, also inadequate mechanical design of the fuse holder mechanism, which were not remedied until November 1935. In spite of, or including these difficulties, analysis of the record for the 1935 season shows at least 20 and perhaps 25 occasions of gaps operating, with a total of 37 blown fuses. During the same period the 110-mile connecting line having very high impulse insulation tripped out due to lightning 33 times. There were at least 8 occasions of gap operations totaling 10 blown fuses without line tripout, and there were at least 12 line tripouts without operation of these gaps.

Although at present this substation is connected to only one line, so that every line tripout causes a service interruption, the foregoing operating data indicate the possibility that had the gaps not been fused there would have been about a 30 per cent increase in the interruptions to service.

On extensive transmission and distribution systems in the Pacific Northwest, where lightning is not prevalent, a large number of plain spill gaps have been installed with settings approximating 2.5 to 3.5 times normal. There are practically no gap operations.

### Protection to Line Insulation

The experience with arc-interrupting gaps along transmission lines has shown that in most cases protection to line insulation and against service interruptions is secured. The first applications of this type of protection, made in Arkansas, continue to give fairly good performance. On the Pine Bluff-Dixie line (110-kv, H-frame, single circuit), approximately 46 miles in length, with arc-interrupting gaps at approximately $^1/_2$-mile intervals, the records show an average of 14.6 tripouts per 100 miles per year from lightning during the 4 years after the installation of these gaps, whereas during the 3 years prior there were approximately 38.0 tripouts per 100 miles per year from lightning. If the 2 periods can be considered otherwise comparable, there was a reduction of 60 per cent in the number of outages caused by lightning.

Another line in Arkansas, from Pine Bluff to Carpenter, (also 110-kv, H-frame, single circuit), 59 miles in length, was constructed with arc-interrupting gaps installed on every structure. This line operating in the same territory as the one mentioned above, shows an average number of outages caused by lightning over a 4 year period of 5.5 per 100 miles per year. Detailed descriptions of these installations were reported by Messrs. McEachron, Gross, and Melvin in 1933.[8]

On 4 sections of 66-kv transmission line in Pennsylvania during the 2 years 1935–1936 the results secured from the use of arc-interrupting gaps are set forth in table II. It will be noted in the case of the 2 lines partially equipped, that only partial protection is being obtained, and that all cases of damage occurred on structures which were not protected by gaps.

Plain gaps of various types for porcelain protection on transmission lines are effective, as is well known.

### Protection to Bus Insulators and Bushings

Analysis of the operating experience records shows that spill gaps properly set and connected, effectively protect bus insulators and bushings.

Out of the many thousands of installations, there have been only a few instances of failure to protect bushings, some of which probably were deteriorated internally.

For example, at one substation on a 132-kv system in Texas, 28-inch gaps (3.5 times normal) are installed on the first and second line structures adjacent to the substation. During 1936, the top half of one oil-circuit-breaker bushing was shattered by lightning, and another similar bushing flashed over. On the 66-kv system in this same territory, one oil-circuit-breaker bushing punctured below the flange, which should have been protected by a 12-inch spill gap (3.0 times normal).

In other locations there have been a few instances where insufficient physical separation existed between a gap and the porcelain it was supposed to protect, with resulting thermal damage to the porcelain.

### Protection to Transformers

With respect to the protection of transformer insulation by spill gaps, a few examples of experience data should be of interest.

On the 66-kv and 110-kv systems in the Carolinas, a rather general application was made during the period from 1929 to 1931 of fused gaps and plain gaps at the line terminals. These gap settings ranged from 12 to 15 inches on the 66-kv lines (3.0 to 3.8 times normal), and from 25 to 30 inches on the 110-kv lines (3.8 to 4.5 times normal). The average number of transformer units that failed from lightning during the 5 years up to and including 1928 was approximately 8 per year. For the 5-year period beginning with 1932 the average number of transformer units that have failed has been approximately 3 per year.

An alarming number of transformer failures occurred from lightning at scattered locations throughout the extensive Mississippi Valley 110-kv system during the years immediately following the major expansion and construction program, with as many as 10 failures in a single year. Where protective levels were previously in the range of from 24 inches to 31 inches they were in almost all cases reduced to 20 inches or less, and the record since of transformer failures from lightning is 1934, 4; 1935, none; and 1936, one.

At a 110-kv station in Arkansas, previously mentioned, there were 2 failures of transformers from lightning prior to 1934. This station is at the end of a 59-mile 110-kv line, equipped with arc interrupting gaps at each structure. In 1934, rod gaps set at 18 inches were installed directly shunting the high-voltage bushings of the 110-kv transformers. Within 3 months after installation there were 7 flashovers of these gaps and one more failure of a transformer. Following this experience there were installed on the switchyard bus, 9 14-inch fused gaps—3 per phase. This installation is located at the switchyard approximately 800 feet from the transformers. The lines connecting the transformers to the switchyard are equipped with overhead ground wires. A second transmission line extending from this switchyard has been in service during 1936. During the last 2 years there have been no further flashovers of the 18-inch gaps at the transformers or transformer failures and there were 14 operations of the 14-inch fused gaps on the bus.

Mention has already been made of a series of transformer failures occurring within several years at a 110-kv substation in Louisiana, with gap settings of from 31 inches to 18 inches. All failures occurred in the low-voltage windings from lightning voltages transmitted through the transformer. The low-voltage windings are connected to cable circuits and not exposed to lightning.

The first failure occurred in March 1931 with ring-ring gaps set at $27^1/_2$ inches adjacent to the substation, on the line structure. In June 1932 rod gaps set at $26^1/_2$ inches were installed on the substation structure and 31-inch rod gaps immediately adjacent to the transformers. Also 4-inch gaps were installed on the low-voltage (13.8-kv) bus. In April 1933 another transformer failed from lightning and on August 15, 1933 2 more transformers failed. The substation and transformer gaps were then changed to a 20-inch setting. At the same time overhead ground wires were installed over the substation and on the 110-kv line for a distance of about 3 miles out. Another failure occurred in April of 1934 and still another in August 1934. Thus there were a total of 6 failures in 4 years.

Fused gaps arranged with 3 sets of fuses for repeater closing were installed in November 1934 with the gap set at 14 inches. Between then and June 1935, 5 operations of these gaps occurred, each one successfully clearing the circuit without interruption to service or transformer failure. A series of switching tests (previously described) were then made and the gap setting arbitrarily reduced to the minimum practicable setting of 11 inches. At the same time the gap settings on the 13.8-kv bus were reduced from 4 inches to 2 inches and lightning arresters were installed on the 13.8-kv phase and tap leads. In the 2 year period since these last changes, there have been no failures of transformers.

## Conclusions

1. Spill gaps are effective as a means of establishing and co-ordinating insulation levels on lines and stations, and affording dependable protection to equipment and insulation, against failure from lightning.

2. The minimum permissible spill-gap settings, for transmission voltages, without adverse effects on service, are less than those previously considered possible.

*a.* The lower limit generally applicable is the equivalent of approximately 3.0 times the normal phase-to-neutral voltage, in terms of 60-cycle flashover

*b.* When extremely low protective levels are necessary or desirable, and preferably where fused gaps may be applied, the minimum permissible limit may be approximately 2.0 times normal

*c.* The foregoing spill-gap settings are associated with experience to date with existing lines and equipment. No conclusion or recommendation is attempted with regard to the application of desirable levels to specific situations or for guiding future practice

3. In the range of distribution voltages, spill-gap settings in terms of times normal voltage to neutral are relatively higher. Experience indicates that this practice is logical and practically necessary because of interference with closely set gaps, also the practice is permissible with the relatively greater prevailing insulation strengths of equipment.

## References

Reference is made to only a few of the most recent papers, in some of which will be found more complete bibliographies covering earlier work.


1. The Thunderstorm, E. A. Evans and K. B. McEachron. *General Electric Review*, September 1936, page 413.

2. Lightning Investigation on Transmission Lines—VI, W. W. Lewis and C. M. Foust. Electrical Engineering, January 1937, page 101.

3. Lightning Currents in Field and Laboratory, P. L. Bellaschi. AIEE, 1935, page 837; discussion, 1936, page 393.

4. Impulse and 60 Cycle Flashover of Rod Gaps and Insulators, Edison Electric Institute *Bulletin*, August 1936, page 351.

5. Breakdown Curve for Solid Insulation, V. M. Montsinger, AIEE, 1935, page 1300; discussion, 1936, page 399.

6. Short-Time Spark-Over of Gaps, J. H. Hagenguth. Electrical Engineering, January 1937, page 67.

7. Modernization of Transmission Lines, AIEE, 1936, page 12; discussion, page 919.

8. The Expulsion Protective Gap, K. B. McEachron, I. W. Gross, and H. L. Melvin. AIEE, 1933, page 884.

9. Proposed Transformer Standards, J. E. Clem. Electrical Engineering, January 1937, page 32.

10. Lightning Protection for Transformers, AIEE, 1936, page 53; discussion, 1936, page 918.

11. Impulse Voltages Chopped on Front, P. L. Bellaschi. AIEE, 1936, page 985.

# System Recovery Voltage Determination by Analytical and A-C Calculating Board Methods

By R. D. EVANS
MEMBER AIEE

A. C. MONTEITH
ASSOCIATE AIEE

THE PERFORMANCE of current interrupting devices on systems is dependent not only on the characteristics of the device itself but also on the characteristics of the system. The voltage rating of the system and the connections at the time of fault have considerable influence on the recovery voltage and in turn on the application of the interrupting device. For example, the last oil circuit breaker to open must be capable of interrupting current under extreme system recovery conditions, while a deion protector tube always has at least the line section on which it is applied, connected at the time of clearing. This means that in considering broadly the current interruption problem it is necessary to have a knowledge of voltage recovery characteristics for a large number of system conditions. Tests can be made for particular system conditions, but this is expensive and it is difficult to obtain data for all possible combinations of faults and system connections. A general analysis taking into account all the factors makes calculations practically impossible, and on account of the complexity, the human factor cannot be overlooked.

It is the purpose of this paper to present a method of obtaining system recovery voltages by setting up the 3-phase system in miniature on the a-c calculating board, applying faults of several types under different system conditions at several locations and actually measuring the recovery voltages. This method permits taking into account the effect of loads, ground and arc resistance, point of applying the fault with respect to the voltage wave, point of interrupting the current, effect of leaving the fault on the system for different lengths of time, effect of different fault locations, or practically any condition that could be experienced on an actual system in commercial operation.

It is proposed in this paper to present a method which extends the work previously done to allow a more general study of systems. The results of general analysis will be presented in a subsequent paper.

## General Discussion of the Recovery Voltage Phenomena

The problem of determining the recovery voltage of a system is merely that of finding the voltage-time curve for the transients in the system that follow the interruption of an arc path. The basic elements of the problem may be brought out by a discussion of figure 1. Assume that the system is subjected to a short circuit in an arc path at the point $F$ and that the current which flows is interrupted at a normal zero point of the current wave. The transient that follows the interruption of the current gives rise to an oscillation in the voltage which reappears across the arc path. If the insulation strength of this arc path when expressed in voltage and time is higher than the voltage produced by the system, the arc path will not be re-established and the fault current will be suppressed at the current zero assumed. The recovery voltage of this simple system may be calculated according to conventional methods. As illustrated in figure 2, the recovery voltage may be considered as the sum of 2 components: (1) a steady-state or forced frequency component, which is determined by the circuit constants and the generated voltage of fundamental frequency, and (2) a high or natural frequency component which is determined by the circuit constants of this system for free oscillation. The latter component is subject to an exponential decrement on account of losses which in the course of time reduce this component to zero. The current and the various voltages and their components for the simple system of figure 1 are illustrated in figure 2.

When a system with several meshes is considered, each mesh has its own steady-state and natural frequency components and these react on each other through their mutual couplings. The resultant recovery voltage curve, therefore, consists of the sum of a steady-state component and a number of natural frequency components, each of which may have different decrements. While the calculation of recovery voltage for extensive systems becomes quite complicated, it should not be considered something mysterious, since the basic phenomenon is quite simple as brought out in the discussion of figure 1.

It is desirable to review the character of recovery voltage from the standpoint of its practical application and to establish the meaning of the terms to be used in the subsequent discussion. For complicated systems, the recovery voltage-time curve may have quite an irregular shape, such as illustrated in figure 3. Curve $A$ applies to one hypothetical system where there is no residual charge left on the system and curve $B$ applies to another hypothetical system having a residual charge. The entire voltage-time relation is generally implied when the term recovery voltage is used. Recovery voltage is of importance depending on the closeness with which it approaches the insulation strength of the particular arc

---

A paper recommended for publication by the AIEE committee on power transmission and distribution. Manuscript submitted March 17, 1937; released for publication April 19, 1937.

R. D. EVANS and A. C. MONTEITH are central station engineers with the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

The authors wish to acknowledge the helpful suggestions of Doctor J. Slepian, particularly in connection with arc phenomena as related to the interruption problem. They also wish to acknowledge the assistance of R. L. Witzke in making the tests and in analyzing the data.

1. For all numbered references see list at end of paper.

path under consideration. The shape of this insulation recovery curve will vary for the different conditions of the arc path and particularly for the different arc interrupting devices. Some insulation strength curves may be of the shape illustrated by curve $C$ of figure 3, which as drawn approaches the system recovery voltage curves near their crest. For such conditions the maximum recovery voltage and the time to crest represent the important part of this system recovery voltage-time curve. Another insulation recovery curve might be of the shape

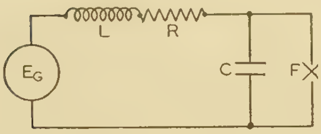
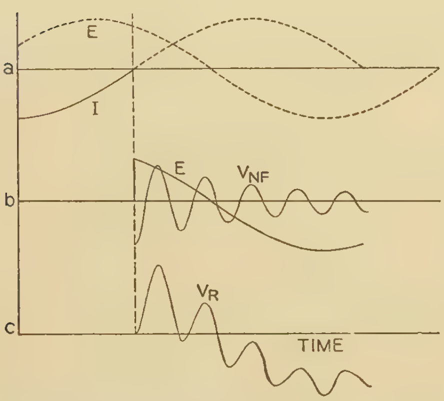



**Figure 1. Simple system for illustrating recovery voltage for a fault F**




*E*—Generated voltage (steady-state value)

*I*—Fault current suppressed at current zero (steady-state value)

$V_{NF}$—Natural frequency voltage component

$V_R$—Recovery voltage

**Figure 2. Voltage and current relations for clearing the fault on the system shown in figure 1**

shown in curve $D$ which comes closest to the system recovery voltage-time curve $A$ at a point close to that of the maximum recovery voltage rate. There is also the possibility that the insulation recovery curve might be of the shape shown by curve $E$ which contacts the system recovery voltage curve $A$ at an intermediate crest between the point of maximum recovery voltage and the point of maximum slope.

From the foregoing it is apparent that for any particular application, the significant factor of the system recovery voltage may be defined in terms of a voltage magnitude and the corresponding time. It is, of course, possible to define the point of interest in terms of a voltage recovery rate and either the corresponding time or the corresponding voltage magnitude. The quantity "recovery voltage rate" by itself is obviously insufficient to define the significant points on either the insulation strength curve or the system recovery voltage curve. Since the term recovery rate is applicable to only a limited range of conditions its general use may become confusing and misleading. For these reasons it has seemed preferable to use the terms recovery voltage magnitude or merely "recovery voltage" and "time to crest" for defining the point of interest on the recovery voltage-time curve and this form of expression is adopted in this paper.

## Part I. Analytical Methods for Calculating Recovery Voltage

There is now available considerable literature on the calculation of transients in circuits involving an a-c source and resistive, inductive, and capacitive branches. In general, the approach is to consider a current circulating in each mesh and to make these currents follow Kirchoff's laws for the transient conditions. Differential equations may be set up and the boundary conditions determined in line with the classical theory. The complete solution is complicated by the necessity of providing for (1) all the possible initial conditions of energy storage in each of the various circuit elements as well as for (2) the various natural frequencies of oscillation and for (3) the various rates of decrement. The mechanical labor of solution

*A*—Recovery voltage curve for system without residual charge

*B*—Recovery voltage curve for system with residual charge

*RR*—Maximum recovery voltage rate for curve *A*

*C*, *D*, *E*—Insulation voltage recovery curves

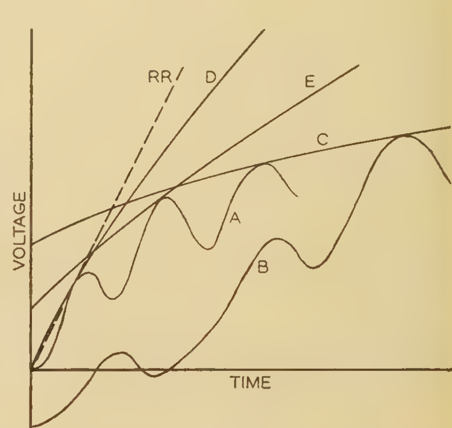



**Figure 3. Comparison of system recovery voltage curves and insulation strength curves**

may be minimized by systematizing the process and an excellent reference is the work by Guillemin.[1]

The conventional method of approach to a solution may be considered as a single-phase method in contrast to the polyphase method to be described subsequently. In the single-phase method the solution may be obtained by assuming a fictitious source of voltage equal in magnitude but of opposite polarity to the voltage existing in the system at the instant of arc suppression, this source being superposed on the actual system and its energy being dissipated through losses in the system. The circuit involves one phase of the power system with return through the neutral and the other 2 phase wires in parallel, and thus it becomes very complicated if many meshes are considered. Such a method has the disadvantage of employing circuits which are difficult to visualize and which will vary for each type of fault; for example, the circuits will be different for a line-to-line fault than for a single line-to-ground fault. Furthermore, the various steps of the solution are also difficult to visualize and the calculations must be carried through in a mechanical manner. In order to avoid a number of these objections a polyphase method utilizing symmetrical components is proposed.

## Transient Analysis by the Method of Symmetrical Components

The application of the principle of symmetrical components to the solution of high frequency transients on polyphase systems constitutes an important step in the simplification of this problem. It will be recalled that steady-state solution of unbalanced faults on ordinary 3-phase power systems was found to be generally impracticable as long as "single-phase" methods of solution were employed. The introduction of the method of symmetrical components by the late Doctor C. L. Fortescue radically changed the status of this problem and the method has come into general use for a variety of applications subsequent to the introduction of the sequence networks. Similar simplification in the solution of high frequency transients is obtained through the use of symmetrical components. In this method the natural frequency components are themselves resolved into positive-, negative-, and zero-sequence components in a manner quite analogous to that employed in the analysis of the ordinary steady-state solution of unbalanced circuits at

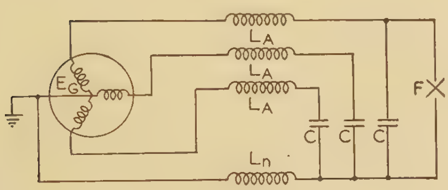



**Figure 4. Simplified 3-phase system subjected to a line-to-ground fault**

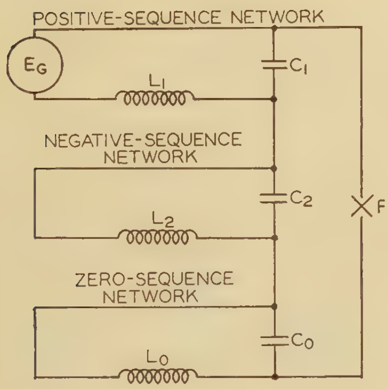



**Figure 5. Connection of sequence networks to simulate single line-to-ground fault. Opening circuit at F simulates clearing of the fault and recovery voltage appears at this point**

fundamental frequency. The advantage of resolving the natural frequency components into their respective sequence components is the same as with fundamental frequency, namely, that the components do not react upon each other in a symmetrical system. The boundary conditions for the natural frequency components are determined, of course, by the dissymmetry of the system occasioned by the fault itself.

In order to illustrate this method a relatively simple system, as shown in figure 4, will be considered. This system is assumed to have a positive-sequence generated voltage $E_G$ in the reference phase with capacitances and inductances in each phase and in the neutral as shown. For this example a fault of the single line-to-ground type is considered. The current is assumed to be interrupted at its normal zero point. The losses in the circuit are ignored and the fault current condition is calculated in the familiar manner making use of the sequence networks.

The manner of setting up the sequence networks for the ordinary circuits containing apparatus and transmission lines, including capacitances and loads is now well established.[2] For a single line-to-ground fault the 3 networks must be connected as shown in figure 5 in order to satisfy the requirements for this particular fault condition. Since by assumption the circuits do not involve loss the resultant current lags 90 degrees behind the voltage of the faulted phase. Consequently, the circuit is interrupted at the zero point of the current wave, the generated voltage on the faulted phase is a maximum, and the various capacitances associated therewith have their maximum charge; the sequence networks are isolated automatically and each oscillates according to its own natural frequency. In the course of time, such oscillations in an actual circuit would be damped out because of the losses. In the case of the negative- and zero-sequence networks, only the natural frequency oscillations are present; in other words, after the fault is removed there are no voltages and currents under steady-state conditions. In the case of the positive-sequence network, however, there is a steady-state solution because of the generated electromotive force and superposed on this is the free oscillation which is determined by the difference in voltage across the capacitances under fault conditions and the value which would be obtained under steady-state conditions. This difference in voltage sets up a free oscillation in the positive-sequence network which in the actual circuit would be dissipated by losses. The total voltage on the faulted conductor consists of several com-

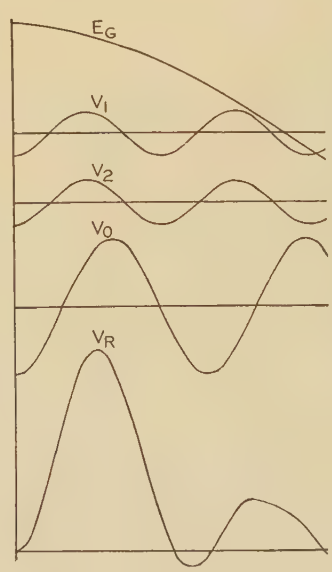



**Figure 6. Components and total recovery voltage-time curve for system of figure 5**

$E_G$—Steady-state voltage
$V_R$—Total recovery voltage
$V_1$—Natural frequency component in positive-sequence network
$V_2$—Natural frequency component in negative-sequence network
$V_0$—Natural frequency component in zero-sequence network

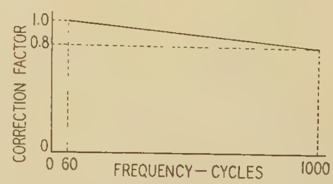



**Figure 7 (above). Frequency correction factor to be applied to the inductance of a synchronous machine. The 60-cycle value corresponds to negative-sequence reactance**

ponents, as shown in figure 6. These include $E_G$, the steady-state voltage due to the fundamental system frequency; $V_1$, the voltage arising from the free oscillation in the positive-sequence network; $V_2$, the voltage arising from the free oscillation in the negative-sequence network; and $V_0$, the voltage arising from the free oscillation in the zero-sequence network. The sum of these voltages must be taken as zero initially in order to fit the fault condition. When the fault is removed these components oscillate according to their respective forced or natural frequencies and the recovery voltage is the sum of the several components and is plotted as $V_R$ in figure 6.

The use of the sequence networks to solve the transient oscillations makes it possible to obtain a better visualization of the phenomena taking place. The various sequence networks may have different natural frequencies of oscillation and different rates of decrement. These considerations make it clear that the shape of the actual recovery voltage curve is in general quite complex. The time to crest and the magnitude of this crest depend on the relation that these oscillating components bear to each other at that instant. Thus, if the several components are in phase the maximum crest is reached. If some of the components of considerable magnitude are in opposition when the remaining components reach their maximum value, the recovery voltage curve is considerably distorted and the crest may be relatively low.

## Representation of System Elements With Lumped Constants

The simple system of figures 4 and 5 can be extended readily to all systems with lumped constants. Question naturally arises as to the necessity for modifying the constants of the circuit elements for representation at high frequencies. Ordinarily these branches, such as machines, transformers, reactors, and capacitors can be represented by inductances or capacitances corresponding to their 60-cycle reactances. In the case of synchronous machines the reactance to be used in the positive- and negative-sequence networks is intermediate between the leakage reactance and the negative-sequence reactance and may be obtained by impressing high-frequency potential on the machine terminals. As the frequency of the impressed voltage is increased the equivalent inductance decreases because of eddy current effects. From the data available the frequency correction to apply to the 60-cycle negative-sequence reactance of the machine is shown in figure 7. The impedance at high frequencies is closely the same for both the positive- and negative-sequence components and, therefore, the same value may be used in both networks.

More accurate representation of the various circuit elements may be required in special cases, as for example, the case in which the recovery voltage is to be obtained on a bus with only the generator connected. For this case it is necessary to determine with some accuracy the capacitance of the bus and the distributed capacitance of the winding. Under such conditions the machine, transformer or reactor representation involves a problem quite similar to that discussed subsequently for circuits having distributed constants. Such refinement in apparatus constants is not required for the usual problem since the effect of these relatively small capacitances is negligible in comparison with the relatively large capacitances of transmission lines, but it is important for the special case of circuit breaker opening, since the analysis is usually made for the case involving opening the last circuit breaker on the bus section.

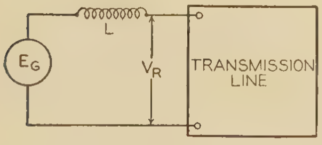



**Figure 8. Transmission line with inductive source**

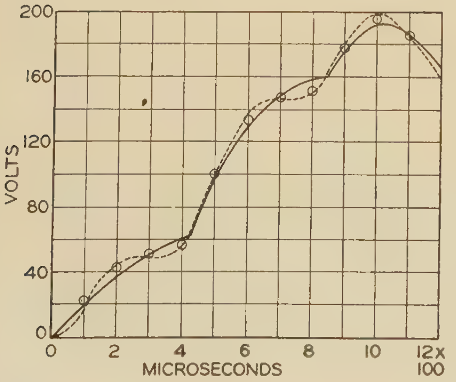



**Figure 9. Calculated recovery voltages for a transmission line with inductive source**

Solid curve—Wave theory
Dashed curve—Equivalent network figure 11a
Circles—Equivalent network figure 11b

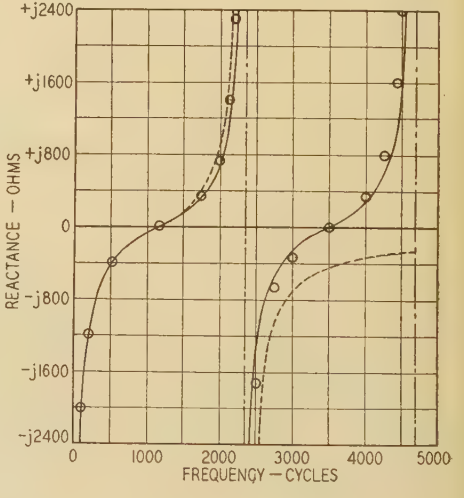



**Figure 10. Frequency - impedance curves**

Solid curve—Transmission line, finite length
Dashed curve—Equivalent network figure 11a
Circles—Equivalent network, figure 11b

## Representation of System Elements With Distributed Constants

Special consideration is required for the representation of a system element having distributed constants, such as a transmission line. The actual transmission line has 3 phases, which may be considered as composed of an infinite number of sections, each with its own self and mutual series impedances and its own self and mutual shunt capacitances. It is possible to use the sequence representation so that the problem reduces from the 3-phase circuit to

that of 3 single-phase circuits with distributed constants, one for each sequence.

The typical case requiring consideration is shown schematically in figure 8 in which $L$ represents the inductance of the source and the square represents the transmission line. If the line were of unlimited length it might be represented by its surge impedance. However, in power work the transmission lines are usually too short to justify such an approximation for determining the maximum crest, although this representation is useful for obtaining the first crest after current zero. The magnitude of the recovery voltage for a particular case of a finite line charged through an inductive source has been calculated by the conventional wave theory and the results are shown in figure 9.

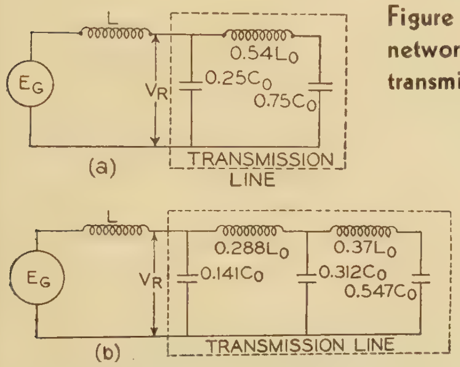



**Figure 11. Equivalent networks for representing transmission line with distributed constants**

(*a*) Single mesh equivalent circuit

(*b*) Two mesh equivalent circuit

$L_0$—Total inductance of line $C_0$—Total capacitance of line

$L$—Inductance of source (not part of network for transmission line)

Such calculations entail too much labor for general use. Hence, it is desirable to represent the transmission lines by a suitable approximation in the form of an equivalent circuit. The approximation need not hold beyond the maximum overshoot and as a matter of fact it need not be accurate throughout this range if it is accurate in both magnitude and time for the particular point on the recovery voltage-time curve that requires consideration. An extremely simple equivalent circuit for transmission lines of finite length consists of an inductance and a capacitance connected in series across the circuit, the combination having the same natural frequency. The recovery voltage of such a circuit will have a time to crest which will be the same as that required for a wave to travel to the far end of the circuit and return.

A more accurate representation by means of equivalent circuits may be arrived at from a comparison of the frequency-impedance characteristics. A transmission line of finite length will have a frequency impedance curve, such as shown by the solid line curve in figure 10; the other curves show the frequency-impedance characteristics of the 2 equivalent circuits shown in figure 11. It will be noted that these circuits have frequency-impedance characteristics which are closely the same as that of the actual transmission line throughout a limited range of frequencies. The calculated recovery voltage curves for the 2 equivalent networks of figure 11 are plotted in figure 9 for convenience in comparison with the recovery voltage calculated by the wave theory. It will be noted

$L_0$—Total inductance of line

$C_0$—Total capacitance of line

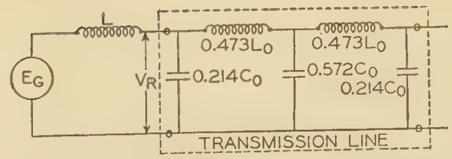



**Figure 12. Double-end equivalent network for representing transmission line with distributed constants**

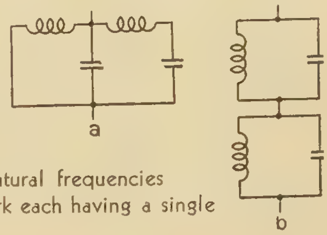



**Figure 13. Network transformations**

(*a*) Two mesh network with 2 natural frequencies

(*b*) Equivalent single mesh network each having a single natural frequency

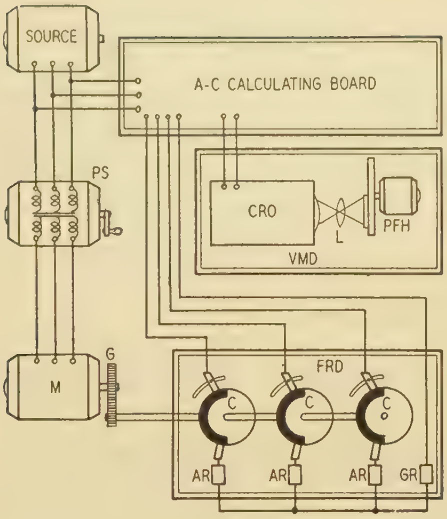
that reasonably good approximation is obtained by these relatively simple equivalent circuits.

For more accurate representation of a transmission line, greater complexity in the equivalent circuit will be required. In general, these networks should be the same for both an open-circuited and a short-circuited receiver. Also, the equivalent circuit should be of the "double-end" type so as to facilitate the introduction as an element in the complete network. One of these double-end networks is illustrated in figure 12.

Another method of studying the equivalence of networks is to compare the simple equivalent circuit with the more elaborate circuit requiring a very large number of series inductance and shunt capacitance elements.

## Solution for Line-to-Ground Fault

The general method of setting up the equivalent circuits for each of the different sequences has already been described. For a line-to-ground fault the 3 sequence networks must be connected in series as shown in figure 5 in order to meet the requirements for the fault condition. When the fault is suppressed, oscillations will take place in each of the sequence networks. The natural frequencies of oscillation for each sequence network and their rates of decrement may readily be computed for the simple circuit shown in figure 5. For more complicated systems it is necessary either to transform the equivalent circuit to a more manageable form or to resort to the conventional solution using differential equations. When the equivalent circuit for each sequence network is not too complicated but is of a form similar to that shown in figure 13*a*, it is usually more convenient to transform it to the form shown in figure 13*b* which facilitates calculation of the natural frequencies of the individual sections. This use of equivalent circuits has been used by E. W. Boehne[3] for calculating recovery voltage by the single-phase method. The transformation depends upon the use of equivalent circuits having the same impedances at all frequencies and a number of such equivalent networks has been worked out by K. S. Johnson.[4]




*PS*—Phase shifter
*M*—Synchronous motor
*G*—Gear
*FRD*—Fault representation device
*C*—Commutator
*AR*—Arc resistance
*GR*—Ground resistance
*VMD*—Voltage measuring device
*CRO*—Cathode-ray oscilloscope
*L*—Lens system
*PFH* — Polar film holder

**Figure 14. Schematic diagram for a-c calculating board method of determining system recovery voltage**

### Solution for Other Types of Faults

For other types of faults the same sequence networks may be used in various combinations. The method of connecting these networks varies with the type of fault and is the same as for the steady-state solution, for example, for the line-to-line fault the positive- and negative-sequence networks are connected in series with the normal direction of fault current flow reversed in the negative-sequence network. For the double line-to-ground fault the connection is the same as for the line-to-line fault except that the zero-sequence network is placed in parallel with the negative-sequence network. From this it is apparent that even the sequence method becomes involved for the more complicated types of faults. It has its greatest advantage in the solution of the line-to-line or line-to-ground faults.

### Limitations of Analytical Methods

Before taking up the ultimate method of solution proposed in the paper it is desirable to consider the further limitations of analytical methods. For example, the initiating transients arising from the application of the fault at voltage crest may not be dissipated before the fault current is suppressed and the resulting subsidence transients begin. In addition, the fault itself may not be single phase in character but may involve several transients, such as those that are incident to the simultaneous opening of each of the 3 poles of a circuit breaker. Further complication arises from the fact that the circuit opening is made through an arc which is not of linear resistance characteristic.

From the foregoing considerations it is apparent that the analytical method of solution is of restricted use. While the method of symmetrical components has simplified the problem for certain types of calculations, many limitations still remain. For this reason a more general method of solution is suggested using the a-c calculating board with connections corresponding to the analytical methods described.

## Part II. Determination of Recovery Voltage by A-C Calculating Board Method

In view of the limitations of the analytical solution of system recovery voltage transients, the method of setting up the system in miniature on the a-c calculating board is proposed. This method has opened the way for the first time to a general investigation of system recovery voltages, practically eliminating the mechanical labor and the human errors unavoidable in analytical solutions of such an involved and complicated nature. The arrangement of apparatus used in this method is shown schematically in figure 14 which includes:

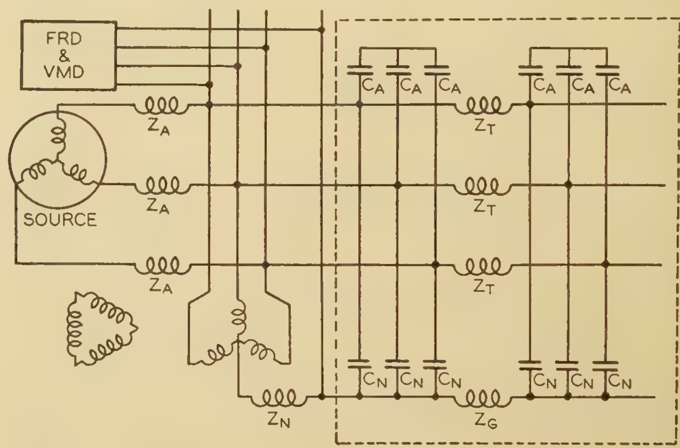



**Figure 15. Schematic diagram for the polyphase method of system representation on the a-c calculating board**

*FRD*—Fault representation device
*VMD*—Voltage measuring device

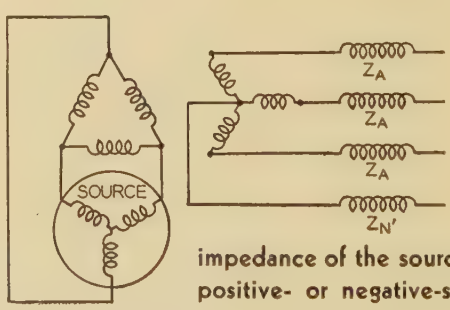



**Figure 16. Schematic diagram of simplified methods for representing power source applicable when zero-sequence impedance of the source is greater than the positive- or negative-sequence impedance**

1. The source
2. A-c calculating board
3. The fault representation device
4. The recovery voltage measuring device

The fault representation device includes means for controlling the point of application of the fault, its duration, and its resistance. To obtain a simple recording device, the transients are made repetitive in character with an

intervening period of sufficient length that one transient does not interfere with the next.

## Connection of A-C Calculating Board

The a-c calculating board used in this investigation has been described in the literature.[5] Two methods of setting up the system on the calculating board are available, namely, (1) the sequence method and (2) the polyphase method. In the sequence method the system is set up in the form of the 3 sequence networks corresponding to the analytical solution of part I. This use of the a-c calculating board merely provides a means for minimizing the mechanical labor that would be required in the analytical method. In the polyphase method the system is set up with a 3-phase source and a 3-phase miniature system. The polyphase method has the advantage of corresponding more closely in form to the original system and it is more convenient since all the phase quantities are included directly in the setup and are available for various fault investigations without manipulation. However, in setting up either method the steps involve the same requirements in the miniature system, namely, that it shall have the same positive-, negative-, and zero-sequence constants for all of the circuit elements requiring consideration.

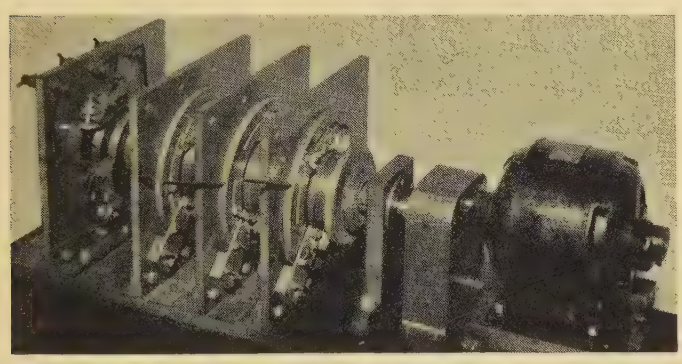


Figure 17. Fault application device, shown schematically in figure 14

In order to illustrate the polyphase method of setting up the system on the a-c calculating board, a more complicated system, such as shown in figure 15, is used. Incidentally, this system is sufficiently representative as to give a reasonably good solution for a large number of problems. Figure 15 applies to a system with a source of power consisting of a generator and step-up transformer, and a transmission line subjected to a fault as indicated. The branches $Z_A$ and $Z_N$ correspond to the generator and step-up transformer constants and the remaining branches correspond to the transmission line when represented by the equivalent $\pi$. The branches $Z_A$ represent the positive- or negative-sequence impedance per phase of the generator and transformer, and the branch $Z_N$ represents one-third of $Z_0$, the zero-sequence impedance of the transformer. If the zero-sequence impedance is higher than the positive-sequence impedance, the source may be represented by a grounded-star transformer with a neutral impedance as shown in figure 16. For this case, as in the previous case, the impedances $Z_A$ represent the positive- or negative-sequence impedance of the generator and transformer. For the neutral branch, however, the impedance $Z_N$ is equal to $(1/3)\ (Z_0 - Z_A)$. In the transmission line similar relations hold for the 3 sequence constants. The positive- or negative-sequence series impedance branch is equal to the impedance $Z_T$ in each phase, and the neutral impedance branch $Z_G$ is equal to $(1/3)\ (Z_0 - Z_T)$. The equivalent capacitance for each end of the $\pi$ representation consists of $C_N$ which is equal to the zero-sequence capacitance for each phase and $C_A$ which is equal to the difference between the positive- or negative-sequence capacitance and the zero-sequence capacitance for each phase.

## Fault Representation Device

The representation of the fault involves 2 elements.

1. The applicator by which the fault is applied and removed.
2. The representation of fault resistance characteristic.

The fault representation device is shown schematically in figure 14 and includes the commutator arrangement $C$ which consists of 3 separate elements, one for each phase. Each element has 2 brushes, one of which is adjustable. The commutator is driven by a synchronous motor connected to a phase shifter supplied from the same source as the a-c calculating board. The fault is established when 2 brushes make contact with the conducting section which spans half of the commutator periphery. The fault is removed when either of the brushes leaves the conducting section. Such a commutator may be built to permit individual control of the instant of application of the fault, but ordinarily it is sufficient to consider the fault applied simultaneously to the 3 phases and this may be done by a set of fixed brushes and a phase shifter. The duration of the fault is controlled by separate adjustment of the brushes which can be set to maintain the fault for different periods from a half cycle to several cycles of the fundamental. The gear, connected between the driving motor and the commutator, makes it possible to apply the fault alternately on a point on a positive wave and on the corresponding point on the

Solid curve—Characteristics of Rectox resistor for fault representation

Circles—Characteristics of deion flashover protector

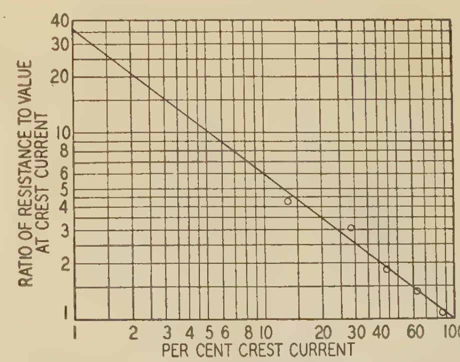



Figure 18. Arc characteristic of deion flashover protector compared with fault representation device

negative wave. The object of the gear is to avoid cumulative magnetizing action in the source. The fault applicator used in this investigation is shown in figure 17.

Consideration will now be given to the means for representing the fault and arc resistances. The first approximation of a fault is a resistance, which is of zero value while the current is flowing, and suddenly changes to infinite value when the current zero is reached. A second approximation of fault characteristics takes into account the tower footing resistance and the arc resistance. This is, of course, readily represented by introducing an appropriate resistance in the fault path through the commutators and in the neutral as shown by the branches *AR* and *GR* of figure 14. A more accurate representation may be accomplished by the use of a resistor whose resistance-time curve would correspond to that obtained from the actual voltage across the arc and the current through it. Such a resistance curve could, of course, be obtained by a synchronously driven commutator which would vary the resistance throughout the cycle. A more convenient and practical device is the Rectox resistor which has approximately the desired characteristic. Two sets of Rectox units oppositely poled are connected in parallel to give the same resistance for either direction of current flow. This combination forms a resistor whose value is relatively low for high currents and relatively high for low currents. It is possible to choose the number of units to give a good approximation of certain arc characteristics throughout the principal part of the arcing period. The arc characteristics and Rectox approximation for a deion flashover protector are shown in figure 18. However, the representation at the end of the interval may not be accurate as the apparent resistance of the arc increases very rapidly at the instant at which the arc is suppressed. For this reason the Rectox resistor has been used in combination with the opening of the fault slightly ahead of normal current zero in order to leave a charge on the system.

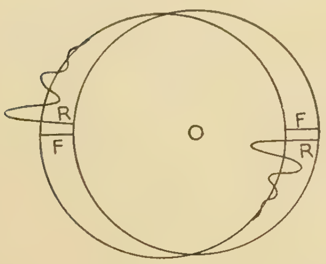



**Figure 19. Polar oscillogram of heavily damped oscillations**

*F*—Point of fault application
*R*—Point of fault suppression

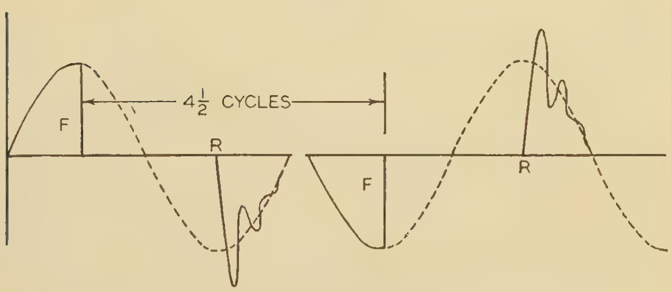



**Figure 20. Cartesian plot corresponding to figure 19**

*F*—Point of fault application *R*—Point of fault suppression

## Recovery Voltage Measuring Device

The transient measuring device for viewing and recording the recovery voltages constituted a major problem. The requirements for the device included accurate response to the various high frequency oscillations, the imposing of small burden on the network always a factor in the use of miniature systems, and means for obtaining a visual trace and a permanent record. The magnetic oscillograph failed to meet all these requirements because an element designed for high frequency response, required a special hookup to avoid placing undue burden on the network. This pointed the way to the use of a cathode-ray oscilloscope which met all the requirements but that of recording. To overcome this difficulty the transient was made repetitive in character by the means just described. On this basis it was readily feasible to photograph the record appearing on the cathode ray screen. The arrangement of apparatus used in most of this work is illustrated in figure 14. The cathode-ray oscilloscope recorded the recovery voltage on its screen and this image was placed on a film through a suitable lens system. While it is possible to photograph the image using the cathode ray sweep circuit to provide the time scale, it was more practical to rotate the film by means of a synchronous motor thus obtaining a uniform time scale on an oscillogram of the polar form.

The type of record obtained for a highly damped transient is shown in figure 19 and the corresponding Cartesian plot in figure 20. The entire oscillogram repeats every 9 cycles and includes 2 applications of the fault indicated at the points *F* which are $4^1/_2$ cycles apart. The faults are impressed for $^1/_2$ cycle and the arcs are suppressed at the points *R* at which the recovery voltages begin to appear. The high frequency oscillations are superposed on the steady-state voltage as shown in the figures, and in this case are damped out in less than $^1/_2$ cycle. If the transient is not highly damped it may persist for many cycles. In general, however, the high frequency oscilla-

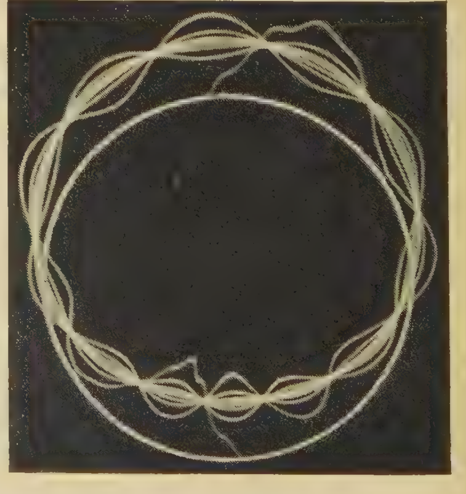


**Figure 21. Typical oscillogram of recovery voltage on a system with lightly damped oscillations**

tion due to the first transient will have disappeared before the second transient is applied. Furthermore, the second transient will be of opposite polarity to the first and this prevents cumulative magnetizing action and minimizes the importance of transients that are left on the system. When the decrement of the high frequency component is small the high frequency wave will persist for more than $1/2$ cycle and this will cause the oscillograms to have several distinct curves as shown in figure 21, which is an actual oscillographic record. It is, of course, possible to use a device to open the oscilloscope circuit or to eliminate all portions of the record except the part required for analysis. However, no difficulty is encountered in picking out the part of the curve desired for study and additional apparatus to simplify the record has not been found necessary.

## Adjustment of the Apparatus

The fault may be applied at any point on the voltage wave by adjustment of the phase shifter. This adjustment is accomplished with the aid of the ordinary cathode ray viewing screen and sweep circuit. The final check is obtained directly on the polar oscillogram itself. The duration of the fault is controlled by the adjustment of the brushes which open the circuit in the vicinity of the normal current zero. This adjustment may be checked by using the oscilloscope to measure the voltage drop across a small resistance in series with the fault. However, experience has shown that this refinement in the adjustment is not generally necessary as the desired point can be determined from examination of the voltage wave alone. It has been found that the fault representation device can be made to open the circuit not only at the normal current zero but appreciably ahead of or back of this point. This, of course, is due to the fact that very low voltage is used on the a-c calculating board or impressed on the commutator and that the commutator itself is capable of developing relatively high insulation strength and thus is able to suppress the arc on either side of the normal current zero. It is of interest that sparking on the commutator takes place if the circuit is not opened at the normal current zero and this provides in itself a convenient form of approximate adjustment. In the case of double faults the procedure is to control first the point of application of the faults by comparison with the desired point on the voltage wave of a particular phase. The adjustable brush is then moved to control the open-

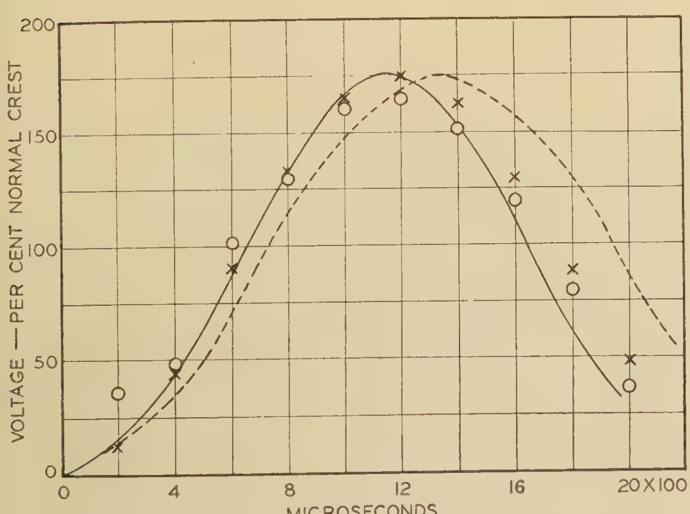



**Figure 22. Comparison recovery voltage measurements and calculations. Line-to-ground fault on Indianapolis Power and Light Company's 138-kv system**

Solid curve—Field test number 26
Dashed curve—Field test number 69
Crosses—Calculation for equivalent "T" network
Circles—Calculation for equivalent network, figure 11a

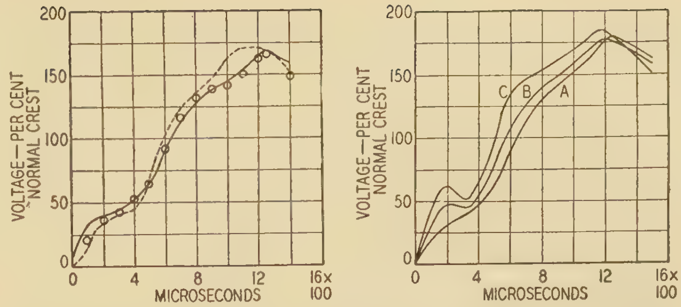



**Figure 23 (left). Comparison recovery voltage measurement on a-c calculating board and calculations. Line-to-ground fault on Indianapolis Power and Light Company's 138-kv system (same condition as figure 22)**

Solid curve—A-c calculating board solution, 3-phase connection
Circles—A-c calculating board solution, sequence network connection
Dashed curve—Calculation for equivalent network, figure 11a

**Figure 24 (right). Effect on recovery voltage of varying the instant of application of fault. Circuit opened at first normal current zero**

*A*—Fault applied at voltage crest
*B*—Fault applied before voltage crest
*C*—Fault applied after voltage crest

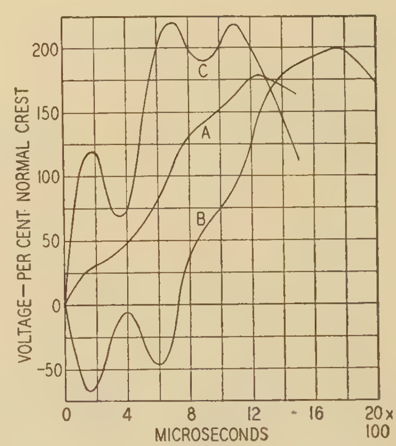



**Figure 25. Effect on recovery voltage opening circuit at different points with respect to normal current zero. Fault applied at voltage crest and circuit opened in vicinity of first current zero**

*A*—Circuit opened at normal current zero
*B*—Circuit opened before normal current zero
*C*—Circuit opened after normal current zero

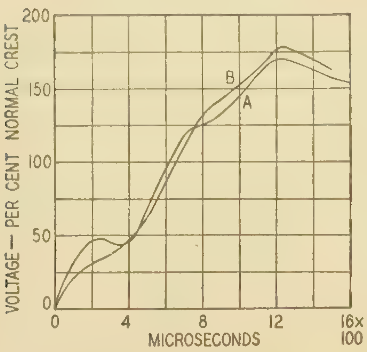



**Figure 26. Effect on recovery voltage of varying the duration of fault**

*A*—Fault duration, 1/2 cycle
*B*—Fault duration, 1 cycle

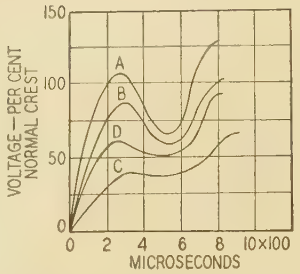



**Figure 27. Effect on recovery voltage of fault and arc resistance. Single line-to-ground fault**

*A*—Zero fault resistance
*B*—8-ohm fault resistance
*C*—33-ohm fault resistance
*D*—Rectox resistor, 5 ohm minimum (see figure 19)

**Figure 28. Effect on recovery voltage of arc interruption with residual charge. Fault simulated by Rectox resistor and circuit opened before normal current zero**

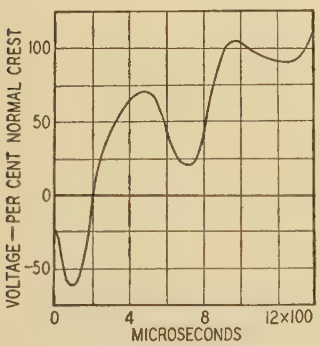



**Figure 29. Effect on recovery voltage of the addition of load**

*A*—Without load
*B*—With load

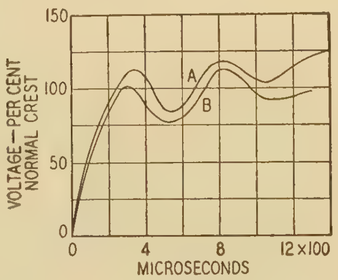
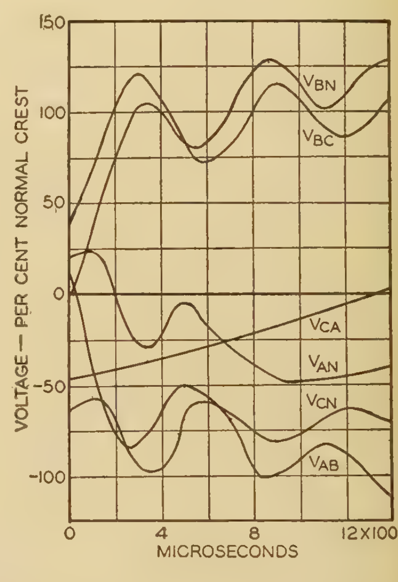



**Figure 30. Transient voltages of 3-phase system upon clearing of single line-to-ground fault on phase B**

$V_{AN}$, $V_{BN}$, $V_{CN}$—Voltages to neutral

$V_{AC}$, $V_{BC}$, $V_{CA}$—Voltages, phase-to-phase




ing of the first phase at its normal current zero and this is followed by a similar adjustment for the second phase.

## Part III. Application of A-C Calculating Board Method and Comparisons With Analytical Solutions and Field Tests

It is now of interest to compare the recovery voltages as obtained by the analytical method and the a-c calculating board method directly with cathode ray oscillograms of tests made on actual systems. It is beyond the scope of this paper to give results of general investigations of system recovery voltage. A few illustrations will be given to show the range of use of the a-c calculating board in analyzing some of the factors.

It was recognized throughout this work that the results would only be of academic interest unless the solutions by the proposed methods provided a satisfactory check with the results of actual field tests. Some tests[6,7,8] made on the Indianapolis Power & Light Companys' 138-kv system included measurements of recovery voltages with a cathode-ray oscillograph. For two of these tests involving a single line-to-ground fault, the system consisted of a generator and step-up transformers connected in star on the high voltage side and grounded through a 50-ohm reactor, and 39 miles of 138-kv line. Figure 22 compares the recovery voltages of these 2 field tests with results of calculations made for identical circuit conditions with the transmission line represented in one case by an equivalent "T" network and the other case by the equivalent network of figure 11*a*. The closeness of these checks made early in the investigation were very encouraging and greatly stimulated the work that followed.

Following the proposal of the a-c calculating board method and the development of the equipment previously described, it was of particular interest to compare results obtained with this method and results obtained by calculation. Figure 23 compares one of the calculated curves of figure 22 with the recovery voltage measurements from the a-c calculating board using the alternative forms of connection. It will be observed that close checks are obtained between field tests, analytical solutions, and the a-c calculating board solutions.

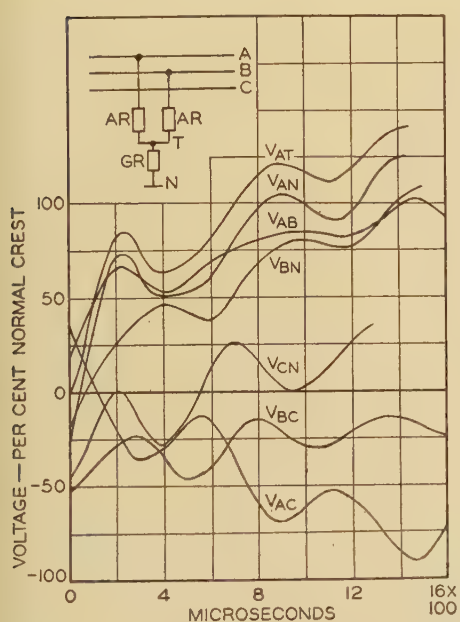
The a-c calculating board method provides an ideal means for carrying out general studies of system recovery voltage. It is, however, beyond the scope of this paper to present results of work along that line. It is pertinent, nevertheless, to discuss the range of application of the a-c calculating board method in this study of the various factors entering into the recovery voltage problem. For this purpose a few illustrations are given to show the ways in which these factors may be studied.

It is of general interest to study the effect of applying the fault at different points on the voltage wave. With the a-c calculating board set up by the 3-phase method to represent the Indianapolis Power & Light Company system, a single line-to-ground fault was applied before voltage crest, at voltage crest, and after voltage crest and was interrupted at normal current zero. The results

of this study are shown in figure 24. Similar studies were made for the fault applied at the voltage crest and the current interrupted before, at, and after the normal current zero. The results of such an investigation are shown in figure 25. These results provide an explanation of the familiar fact that interrupting devices tend to operate at normal current zero. They illustrate further the difficulties of attempting to interrupt a circuit in less than one-half cycle.

The effect on the recovery voltage of varying the duration of the fault is shown in figure 26. This comparison brings out the fact that the shorter the duration of the fault the more important will be the results of the initiating transients on the recovery voltage.

The effects that arc resistance has on the interruption problem have always been of interest. Figure 27 shows the effects of adding different tower footing resistances of fixed resistance values as well as the effect of adding a resistance of varying value, such as shown in figure 18, to simulate the arc. This study was made for a 138-kv impedance-grounded system with 90 miles of line, the system being capable of supplying short circuit current of 4,000 amperes at the sending end.




$V_{AN}$, $V_{BN}$, $V_{CN}$—Voltages to neutral

$V_{AB}$, $V_{BC}$, $V_{CA}$—Voltages, phase-to-phase

$V_{AT}$—Voltage across arc representation device

$A_R$—Arc representation device

$G_R$—Ground resistance

**Figure 31. Transient voltage of 3-phase system upon clearing of double line-to-ground fault on phases A and B. Fault applied at crest of B phase voltage. Phase B and then phase A opened at first normal current zero points. Curves include the highest transient voltages for the opening of phase A or B. (Curves start at an arbitrary zero time)**

In order to simulate arc and fault characteristics in a more accurate manner for the condition in which a residual charge is left on the system, tests were made with the Rectox resistor in the circuit to simulate the arc throughout most of the cycle and the circuit was opened slightly ahead of current zero to simulate the very abrupt change of resistance at current zero. Figure 28 shows the results of a test which simulate a deion flashover protector when interrupting its full current rating.

The effect of load on the recovery voltage can readily be studied on the a-c calculating board and figure 29 shows a comparison of recovery voltage for zero load and for full load on the 90-mile 138-kv system.

It is of interest to have a knowledge not only of the voltage on the faulted conductor but also on the other conductors to neutral as well as between conductors. Figure 30 shows transient voltages for the 90-mile 138-kv system when clearing a line-to-ground fault on phase *B*.

On account of the complexity of the problem it has been practically impossible to get a co-ordinated picture of the transient voltages on the various conductors to ground and from conductor to conductor for a double line-to-ground fault condition. The a-c calculating board method has given a relatively simple approach to this problem and results of such a study for the 90-mile 138-kv system are shown in figure 31. Only the sections of the various transient voltage curves which are of an abnormal nature are shown, the plot starting at an arbitrary zero time in order to simplify the figure.

## Conclusions

1. The symmetrical components method proposed constitutes a simplification of the analytical solutions.

2. The a-c calculating board method is a practical means of determining the electrical transients of systems.

3. The combination of these methods has for the first time opened the way to a systematic general investigation of recovery voltage transients and related problems.

## References


1. Communication Networks (a book), Ernest Guillemin. Volume I. John Wiley and Sons, New York, 1931.

2. Symmetrical Components (a book), C. F. Wagner and R. D. Evans. McGraw-Hill Book Company Inc., New York, 1933.

3. Determination of Circuit Recovery Rates, E. W. Boehne. AIEE Transactions, May 1935, pages 530–9.

4. Transmission Circuit for Telephone Communication—Methods of Analysis and Design (a book), K. S. Johnson. D. Van Nostrand Company, New York, 1927.

5. An Alternating Current Calculating Board, H. A. Travers and W. W. Parker. *Electric Journal*, May 1930, pages 266–70.

6. Building a New Power System, F. S. Douglass and A. C. Monteith. *Electric Journal*, March 1933, pages 192–8.

7. Testing a Power System, A. W. Hill. *Electric Journal*, March 1933, pages 45–8.

8. Transmission Line Transients, W. E. Berkey. *Electric Journal*, August 1934, pages 331–4.

9. Extinction of an A-C Arc, J. Slepian. AIEE Transactions, October 1928, page 1398.

10. Circuit Breaker Recovery Voltages, R. H. Park and W. F. Skeats. AIEE Transactions, 1931, page 204.

11. Circuit Breaker Field Tests on Oil Blast Explosion Chamber Oil Circuit Breakers, R. M. Spurk and H. E. Strang. AIEE Transactions, June 1931, page 513.

12. Oil Circuit Breaker Tests, Philo, 1930, P. Sporn and H. P. St. Clair. AIEE Transactions, June 1931, page 498.

13. Arc Extinction Phenomena in High Voltage Breakers Studied With a Cathode-Ray Oscillograph, R. C. Van Sickle and W. E. Berkey. AIEE Transactions, volume 52, 1933, page 850.

14. Oil Circuit Breaker Voltage Recovery Tests, W. F. Skeats, E. J. Poitras, and H. P. Keuhni. AIEE Transactions, February 1935, page 170.

15. Breaker Performance Studied by Cathode-Ray Oscillograph, R. C. Van Sickle. AIEE Transactions, February 1935, page 178.

# Vibration-Measuring Instruments

## Fundamental Considerations in Their Design

By C. D. GREENTREE
ASSOCIATE AIEE

### Synopsis

A general-purpose wide-range high-precision vibration-measuring instrument must embody several fundamental design requirements which determine the useful frequency range, the accuracy of measurement, the intensity of vibration to which it can be applied, and the effect of the instrument on the vibrating body.

In this paper the advantages and disadvantages of certain mechanical and electrical detecting and amplifying systems for the measurement of vibration amplitude, velocity, and acceleration, are discussed in the light of their design requirements.

A vibration generator capable of producing sinusoidal vibrations over a wide frequency and amplitude range, and a set of vibration standards with which the vibrations produced can be accurately determined, are also described.

In conclusion, criteria for evaluating the performance of vibration measuring instruments of different types are suggested.

AN ever-growing demand for smaller and more accurate vibration measuring instruments has intensified design and development activities in this direction. This increased interest is due in part to the destructive possibilities of vibration on modern high-precision machinery and in part to an awakened recognition of the tremendous nuisance effect of unconfined vibrations.

The interest thus aroused has lead directly to more exacting specifications on the part of those who purchase vibrating or rotating equipment. To meet such specifications has required vibration instruments having increased sensitivity, greater portability, and broader operating ranges, which can be applied to ever-widening fields of investigation.

The general term "vibration instruments" is capable of considerable division and subdivision. The first broad classification can be labeled "precision measuring" as distinct from "vibration detecting." By vibration detecting is meant a device that will simply show that vibration is present or is not present. The mechanical or electrical output from such an instrument may be proportional to the relative amount of vibration over a limited frequency range and still be far from the precision concept.

Precision measuring vibration instruments can in themselves be roughly separated into 2 broad application classes. In one group can be placed all those highly technical and very special instruments built and designed to emphasize or surmount unusual vibration requirements. Practically every extensive vibration investigation program will require one or more of these special instruments, and in general a skilled vibration engineer is necessary to use them successfully. In the other broad division can be included all the general purpose devices. These are characterized by broad operating range, relatively low cost, and a susceptibility to particular adaptations, such as, permanent mounting, recording, and telemetering.

### Types of Instruments

Subsequent discussion will be confined to these general purpose precision measuring vibration instruments. Another subdivision into the 3 main aspects of vibration is required. Three different types of instruments are required for measuring amplitude, velocity, and acceleration. Frequency may be considered more of a condition than an aspect. The first type measures the double amplitude of vibration, or the amount of physical displacement of the vibrating body independent of the frequency or rate of moving.

A velocity type of instrument measures the product of vibration frequency and amplitude, or the rate of vibratory motion. This type of measurement is often convenient, since the vibration energy of the moving body is proportional to its velocity squared. Acceleration depends, of course, on the change in the rate of movement and an acceleration measuring device has an output proportional to the product of amplitude times frequency squared.

These 3 types of instruments are all subject to certain limiting mechanical factors. Some of the most important of these factors are:

(*a*) Establishment of a point stationary in space against which to measure

(*b*) Low natural frequency

(*c*) High structural resonance

(*d*) Ability to follow large accelerations

(*e*) Small effect on vibrating body

(*f*) Measurement in any direction

(*g*) Light weight and portable

### Mechanical System

Perhaps the most fundamental requirement of a general purpose vibration instrument is the creation of a

A paper recommended for publication by the AIEE committees on instruments and measurements, and electrical machinery. Manuscript submitted March 23, 1937; released for publication April 10, 1937.

C. D. Greentree is engineer on development work with the General Electric Company, Schenectady, N. Y.

1. For all numbered references see list at end of paper.

point or body stationary in space relative to which the vibratory motion can be measured. A vibrationless object, which can be used as a reference base, is seldom found ready to hand on the job, and usually is too costly to warrant construction. The establishment of such a stationary mass can be obtained in instruments, by the compliance coupling of a mass to the vibratory motion. The fundamentals of such a scheme are shown in figure 1*a*. The stationary mass $M$ is supported from the moving mechanism $R$ which is in contact with the vibrating body $B$, by the coupling spring $S$. The direction of vibration is shown by the double-headed arrow marker. At the point $A$, between the end of the moving mechanism and the stationary mass, any one of several mechanical or electrical methods for obtaining a measure of the relative motion between the 2 parts can be interposed.

Figure 1*b* shows the electrical equivalent of this mechanical system. The current $i_1$ represents the vibratory motion applied to the instrument. Neglecting $L_1$ and $C_1$ for the moment, the current $i_1$ will divide between $C_2$, representing the compliance of the coupled system, and $L_2$ representing the mass $M$. When the frequency of the applied current is more than 5 times the resonant frequency of the network including $L_2$ and $C_2$, the impedance of $C_2$ has become very small compared to the impedance of $L_2$, and substantially all the current flows through $C_2$.

The coupling spring represents the heart of the mechanical system. Under the action of gravity or inertia, a given mass will oscillate on a given spring at a certain natural frequency. Conversely, if the end of the spring is driven by a vibration having a frequency equal to or nearly equal to the natural frequency just determined, a condition of resonance is set up and the mass, instead of remaining stationary in space, will tend to vibrate at tremendous amplitudes limited only by the friction of the spring and the inertia and friction of the supporting hand and arm in which the mass may be held. Mechanical system resonances are, in general, sharply peaked, and experience has shown that the mass will remain substantially stationary when the end of the spring is driven at a frequency from 4 to 5 times the natural frequency of the system. In a great deal of vibration work, it is desirable to be able to measure down to 10 vibrations per second, equivalent to 600 rpm. This means that the natural period of the mass on its coupling spring should be from 2 to $2^1/_2$ vibrations per second.

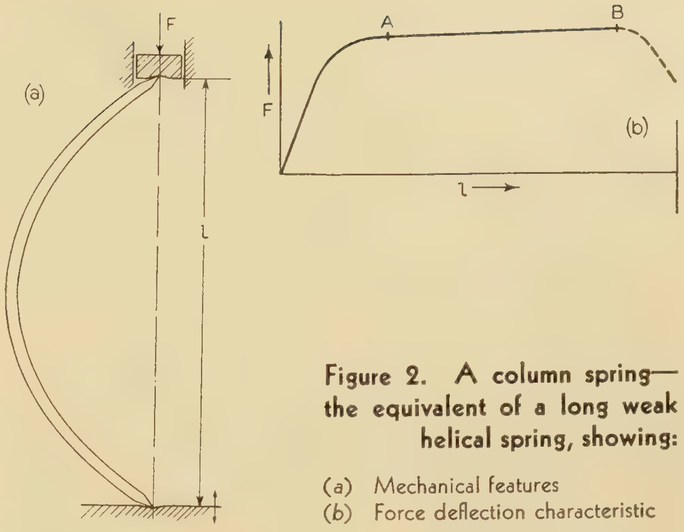



**Figure 2. A column spring—the equivalent of a long weak helical spring, showing:**

(*a*) Mechanical features
(*b*) Force deflection characteristic

The formula[1] for the natural frequency of such a mechanical system is given by:

$$f = \frac{1}{2\pi}\sqrt{\frac{Kg}{W}} \text{ or } K = \frac{W}{g}\,\omega^2$$

where

$f$ = vibrations per second
$W$ = weight
$g$ = gravity acceleration
$K$ = spring constant of coupling spring

If $f$ is to be small, 2 to $2^1/_2$ vibrations per second, and $W$ must also be small, for lightness and portability, it is apparent that $K$ will be small, representing a weak spring. To avoid fatigue and failure due to excessive stress in the outer fibers of the spring, it will be necessary to make this spring relatively long. A long, weak spring is difficult to contain in a small space.

Thus, one of the most active lines of endeavor in the design of vibration instruments has been to produce the equivalent of a long weak spring, which can be contained in a small space and which will not permit too great relative movements between the mass and the driving mechanism.

One such equivalent is shown in figure 2*a*. When a force, continually applied along the original major axis of the column, has compressed the spring beyond a certain point, further compression increases the spring resisting moment arm[2] and the external eccentric loading moment arm by approximately the same amount. This means that a very small change in pressure will cause a relatively enormous change in effective length of the column. The force versus effective length characteristic of such a spring is shown in figure 2*b*. The spring constant of the column, as shown by the slope of this curve between the points $A$ and $B$, is very small.

Another method[3] for supporting a mass on springs at a low natural frequency is shown in the negative compliance system of figure 3*a*. Movement of the mass toward the left causes a compression of the spring $A$ and

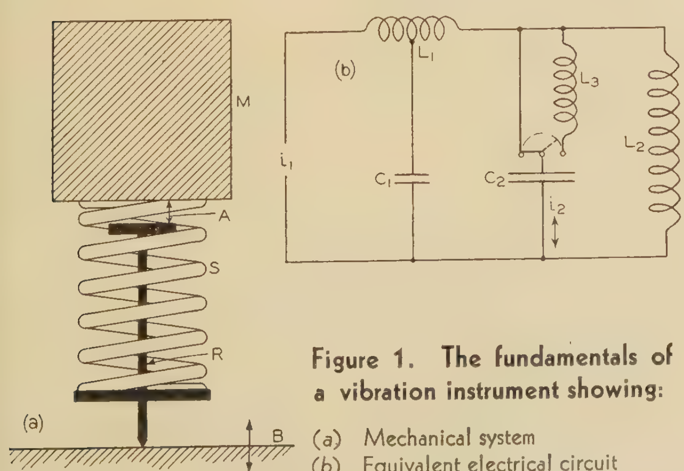



**Figure 1. The fundamentals of a vibration instrument showing:**

(*a*) Mechanical system
(*b*) Equivalent electrical circuit

Table I. Vibration Amplitudes and Velocities Corresponding to an Acceleration of 25 Times Gravity

| f = Vibrations per Second | D = Double Amplitude (Displacement) in Inches | V = Maximum Velocity (Inches per Second) |
|---|---|---|
| 10 | 4.89 | 154 |
| 60 | 0.136 | 25.6 |
| 200 | 0.0122 | 7.65 |
| 1,000 | 0.000489 | 1.54 |
| 4,000 | 0.0000305 | 0.385 |

a lengthening of the spring $B$, thus producing resisting forces vectorially represented by $A$ and $B$ in figure 3*b*. At the same time, the ends of the knife-edge links bearing on the mass are displaced toward the left. The pressure of the springs $F$-$F$ tends to continue the movement of the mass toward the left. By the proper adjustment of the relative compression forces exerted by all the springs, the component of the knife-edge linkage forces $F$, which opposes the resultant of forces $A$ and $B$, can be made to balance or very nearly balance the resisting force of spring $A$ and spring $B$. This will hold, of course, only so long as the angle $\theta$ is small so that this opposing component is substantially equal to $2F\theta$. The force deflection characteristic of this system is shown in figure 3*c*.

## High Structural Resonance

The measurement of vibrations of high frequency, requires a mechanical transmission path from the point at which the vibration is contacted to the point within the instrument at which the measuring takes place, which will be free from structural resonances at any frequency lower than the highest frequency to which it is desired to measure. Structural resonance will occur at that frequency at which the distributed mass of the moving system, as represented in the equivalent electrical circuit, figure 1*b* by $L_1$, resonates with the distributed compliance, as represented by the lumped value $C_1$. When this occurs, the current through capacitor $C_2$ is no longer a true indication of the current $i_1$.

The surmounting of this difficulty requires a stiff yet light transmission system which can be obtained by keeping the transmitting member as short and small as possible and utilizing an inherently high resonance shape, like a rod or tube driven longitudinally.

## Ability to Follow Large Accelerations

In order to meet the prerequisites for a wide range general purpose instrument, it must be possible to hold the spring-coupled contact rod in contact with the vibrating object during accelerations many times that of gravity. Experience has shown that an ability to follow up to an acceleration of 25 times gravity would be generally acceptable for most types of work. In certain cases, such as the vibrations of an unbalanced high-speed spinning motor shaft, which sometimes exceeds 70 times gravity, much higher accelerations may be encountered. Table I shows an acceleration of 25 times gravity expressed in terms of double amplitude of vibration at several different frequencies.

Applying the known equation,

$$F = MA, \text{ or } A = F/M$$

where

$A$ = acceleration
$F$ = force
$M$ = mass

to figure 1*a*, it is evident that for $A$ to be large, $F$, the pressure exerted by the coupling spring, must also be large, and the mass of the moving mechanism, $R$, must be small. In the equivalent electrical circuit of figure 1*b*, $L_1$, which represents the mass of the moving mechanism, must be small.

## Small Effect on Vibrating Body

Since a general purpose instrument should be applicable to any vibrating body from a massive turbine shell down to a $^1/_{100}$ fractional-horsepower motor frame, it is desirable to have the moving mechanism of the instrument produce as little effect as possible on the vibrating body. This is particularly true when dealing with light bodies which are vibrating at, or near, resonance. When the contact rod is pressed against a vibration, the mass of the moving mechanism, and part of the mass of the spring, are effectively coupled to the vibrating body. Thus, the smaller the mass of the moving system the smaller will be the effect on the vibrating body.

In addition to this mass loading condition, the pressure of the coupling spring, acting through the contact rod, may set up stresses in the vibrating body which will materially affect its vibratory motion. This is especially true in the case of resonant vibration of thin bodies such as the walls of an air duct.

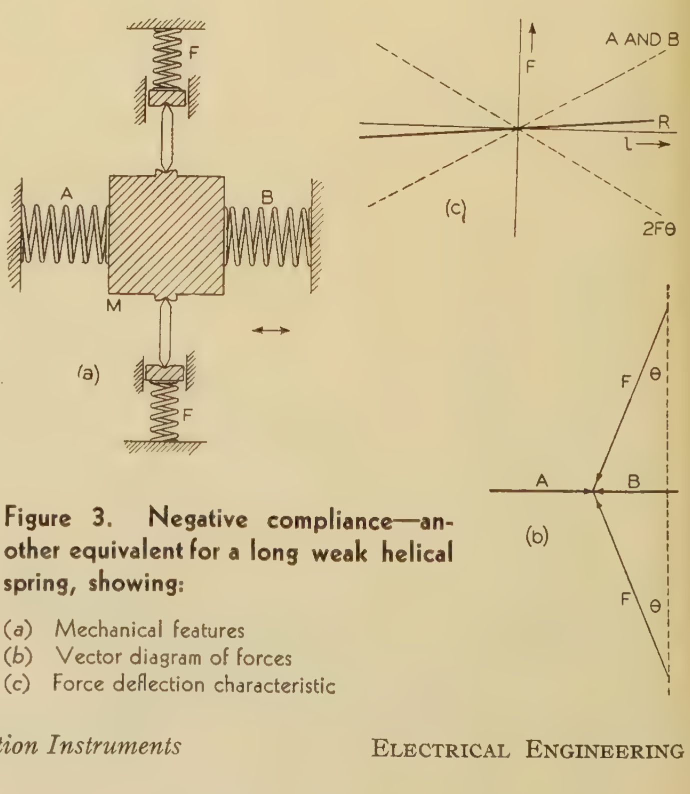



Figure 3. Negative compliance—another equivalent for a long weak helical spring, showing:

(a) Mechanical features
(b) Vector diagram of forces
(c) Force deflection characteristic

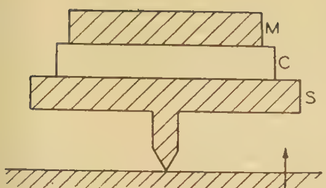



Figure 4 (above). A piezoelectric crystal used for the measurement of vibration acceleration

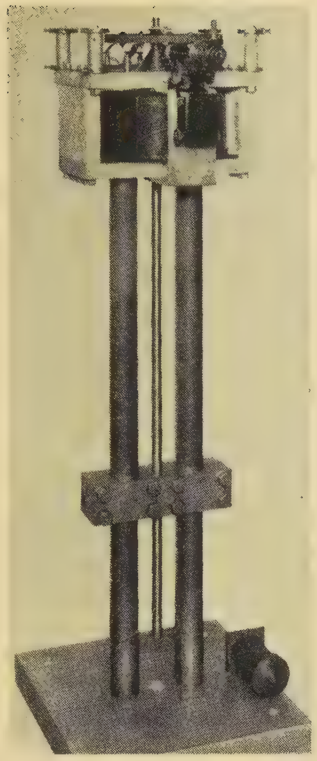


Figure 5 (right). Vibration generator

Both the ability to follow a large acceleration and the attainment of a small effect on the vibrating body call for a moving mechanism of small mass, but in the former a strong spring is needed while the latter requires a weak one. One way to obviate this difficulty is to provide an adjustable spring or springs, the pressure of which can be increased when it is desired to measure large accelerations. In general the acceleration of small bodies under resonance conditions will be small, thus permitting the use of a relatively weak adjustment of the spring. On somewhat larger bodies which are capable of handling much greater vibration energies, and hence producing larger accelerations, it is permissible to increase the spring pressure.

## Sensitivity

Modern requirements as written into rotating machinery specifications sometimes call for the limitation of vibration amplitudes to values less than 0.0001 inch. In addition to these mechanical requirements, it must be remembered that the awakened interest in noise calls for vibration measuring instruments of even greater sensitivity. A vibration amplitude of one millionth of an inch at 1,000 vibrations per second will produce an appreciable noise. The attainment of such sensitivity depends upon the electrical or mechanical measuring means which are interposed between the stationary mass and the moving mechanism of figure 1*a*.

## Mechanical Measuring Systems

A load, small in comparison with the inertia of the stationary mass of figure 1*a*, can be connected between the moving mechanism and the mass. This load, for example, may be an amplifying mechanical lever, gear train, or light-beam system adapted to greatly magnify the vibratory motion.

This load, in effect, is simply a continuation of the mechanical system already outlined, and its parts are subject to similar requirements of light weight, structural stiffness, etc. Referring to figure 1*b* the moving mass added by this load will increase $L_1$, while the lack of stiffness in its parts will increase $C_1$, thus increasing the effect on the vibrating body and reducing the ability of the instrument to follow large accelerations.

The reaction of the moving parts on the stationary mass $M$, to which they are connected, can be represented by the addition of an inductance $L_3$ in series with $C_2$. When $L_3$ is an appreciable fraction of $L_2$, which it may be when the lever amplification is large, some part of the current $i_2$ will shunt through $L_2$ and be lost for measurement purposes. Under these conditions $L_2$ is no longer stationary in space, but has some movement.

It is almost impossible to construct a mechanical system of large amplification which will at the same time be rigid and have small inertia. In addition the friction and lost motion at the joints will seriously limit the accuracy of the instrument.

Until ways are found to circumvent this practical difficulty, purely mechanical systems will continue to be restricted to vibrations of relatively low frequency, of the order of 50 vibrations per second or less, and amplitude measurements of the order of one mil or larger.

## Electrical Measuring Systems

By making the stationary mass $M$, figure 1*a*, a magnet which surrounds a coil rigidly attached to the moving mechanism, it is possible to generate a voltage proportional to the velocity of the vibrating body and at the same time add very little mass to the moving mechanism and introduce but a very small amount of reaction on the stationary mass. The inherent sensitivity of this electrical method depends, like all a-c generators, on the establishment of a high flux density and a high coil space factor. Furthermore, the enormous amplification obtainable from vacuum-tube amplifiers has no deleterious effect on the fundamental mechanical system, nor are serious frequency limitations introduced by the amplifying means.

This system is admirably adapted to the measurement of vibration velocity. It can, by the use of a frequency analyzer, be used to measure amplitude, but the process is apt to be laborious, especially when dealing with nonsinusoidal vibrations.

An electromechanical method for the direct measurement of acceleration is shown in figure 4. The mechanics of this system differ from those shown in figure 1*a*. A piezoelectric crystal $C$ is cemented to a stiff member $S$ which can be held in contact with the moving body, and a heavy metal block $M$ is cemented to the back of the crystal. Under conditions of vibration the block $M$, due to inertia, will produce alternating pressure and tension on the crystal. The amount of pressure and tension depends directly on the mass of the block $N$ and the acceleration of the vibration.

The voltage, proportional to pressure, generated by the piezoelectric crystal, can be amplified in the same

manner as the output of the velocity type of instrument.

In contrast to the amplitude and velocity instruments the whole mass of this acceleration device, including the hand which holds it in contact, will appear as a load on the moving body, thus reducing the maximum acceleration to which it can be applied. This difficulty can be surmounted in part by making the crystal and the mass *M* very small.

The measurement of velocity or amplitude by this crystal method requires, respectively, a single or a double integration of the output.

## Vibration Testing Equipment

For the design and development of vibration instruments, it is vitally necessary to have a known controllable source of sinusoidal vibration. A great deal of time and effort have gone into the production of the vibration generator shown in figure 5. The output from a beat-frequency oscillator is stepped up by means of a 250-watt power amplifier and fed to a specially constructed moving coil which operates in an electromagnet field in the same manner as a loudspeaker. This edgewise-wound aluminum driving coil is capable of dissipating the full 250 watts of power at elevated temperatures. The motion of the coil is transmitted through a steel cone to the driving rod which projects from the top of the generator. The whole moving system is suspended in the air gap by means of steel piano wires under tension. Objects to be tested rest on, or are bolted to, this driving rod.

Such a generator is capable of producing amplitudes up to $^1/_4$ inch at vibration frequencies from 10 to 200 per second. At higher frequencies, up to 3,000 vibrations per second, proportionately smaller amplitudes are obtainable. Above 1,000 cycles the driving rod is locked to the resonance rod which extends downward between the supporting pillars. This resonance rod can be solidly clamped to the supports at any point throughout its length. When it is desired to vibrate the driving rod at say 2,000 vibrations per second the resonance rod is clamped at that length at which the natural longitudinal resonant frequency of the rod and driving mechanism equals 2,000. Two-thousand-cycle power applied to the driving coil will now produce relatively large movements of the driving rod. The amplitudes attainable are limited mainly by the internal friction of the resonance rod and its associated structure. Accelerations exceeding 70 times gravity have been measured and these when using only a small part of the total available power.

## Vibration Standards

Accurate determinations of the vibrations produced by this generator are obtained by means of primary and secondary standards. The secondary standard of frequency, the beat-frequency oscillator, can be checked when desired against primary frequency sources.

Amplitudes greater than 0.0005 inch are measured with a microscope equipped with a filar micrometer eyepiece. A spot of light reflected from a point on the moving generator drive rod produces a bright line in the microscope field. The length of this line, which is the amplitude of vibration, can be measured with great accuracy.

The determination of amplitudes below the microscope range is accomplished in 2 ways. A coil rigidly attached to the upper end of the drive rod, and partaking of its motion, generates a voltage by interaction with the surrounding field from a permanent magnet. This voltage is proportional to the velocity of vibration. By means of a high-gain amplifier, very small velocities of the driving rod can be measured. The calibration of this tertiary working standard coil and amplifier can be checked at one end of the amplitude range with the microscope, and at the other end by means of an acceleration device dependent on the constant of gravity.

A single point check can be made in a more fundamental manner. A hardened steel ball set on a hardened steel plate attached to the driving rod, will maintain contact with the plate when the acceleration of the driving rod is less than gravity. By passing a small current between them it is possible to accurately determine the exact point at which the driving rod reaches gravity acceleration, and the ball loses contact with the plate. At 2,000 vibrations per second this will occur at an amplitude of $1 \times 10^{-5}$ inches, approximately $^1/_{50}$ of the amplitude which can be measured accurately with the microscope.

## Conclusions

1. The growing need for general-purpose wide-range high-precision vibration measuring instruments makes it desirable to establish a systematic method of evaluating the performance obtainable from different types of instruments.

2. Three separate instruments or an instrument with 3 adjustments are required to measure the 3 different aspects of vibration; i.e., amplitude, velocity, and acceleration.

3. The natural frequency of the mechanical coupling system should not be greater than $^1/_4$ of the lowest frequency it is desired to measure.

4. The frequency of moving structure resonances should be considerably higher than the highest frequency to be measured.

5. The instruments should be capable of measuring vibration accelerations as high as 25 times gravity and should not have any large loading effect on the vibrating body.

6. Existing mechanical vibration amplitude measuring systems have undesirable frequency and sensitivity limitations.

7. Electrical generating and amplifying systems are well suited to the measurement of vibration velocity.

8. Wide range vibration generating equipment and accurate calibration standards are necessary for the development of high-precision vibration-measuring instruments.

## References


1. Vibration Prevention in Engineering (a book), Arthur L. Kimball. John Wiley & Sons, Inc., 1932, page 7.

2. Strength of Materials (a book), James E. Boyd. McGraw-Hill Book Company, third edition, 1924, page 250.

3. Dynamic Balancing of Rotating Machinery in the Field, E. L. Thearle. ASME *Transactions*, volume 56, October 1934, pages 745–53.

4. A New Portable Meter for Noise Measurement and Analysis, W. O. Osbon and K. A. Oplinger. *Journal* of the Acoustical Society of America, volume 5, July 1933, pages 39–45.

# Basic Impulse Insulation Levels

## A Report* of EEI-NEMA Joint Committee on System Insulation Co-ordination**

As a RESULT of a great deal of operating experience and from a survey of the then current practice as regards insulation of high-tension equipment, it began to be evident some 9 years ago that too little, if any, attention had been paid to co-ordination of insulation in power systems. Apparatus was being built to specifications which were primarily formulated on a 60-cycle basis, with consideration given mainly to the ability of the apparatus to withstand 60-cycle voltages and almost no consideration to impulse strength. Further, very little consideration was given to insulation margins between the different types of apparatus used on the same system voltage. This was first brought to the attention of the membership of the AIEE in 2 papers presented some 9 years ago.

The subject of insulation co-ordination thus brought into the open, was discussed rather extensively in committees by users and manufacturers and before the Institute for the next 2 or 3 years. Very little progress was made, however, owing to the complexity of the problem and the fact that several different industry interests were involved. Eventually this was recognized, and this led to the formation in 1931 of a joint NELA-NEMA committee to act upon the entire broad subject. The work of the NELA group was transferred to the Edison Electric Institute group when it was formed in 1933.

## Purpose and Scope of the Committee

When active work was started on this subject in 1931, the following statement of principles was made by the NELA (now EEI) group.

"The co-ordination of insulation involves 3 steps:

1. Establishment of insulation levels.

2. Specification of insulation strengths of all classes of equipment in establishing insulation levels.

3. Allocation of the insulation levels to the nominal system voltages taking into account all operating and environmental conditions."

## Activities of Committees

Without going into the details of the various meetings held and the subjects discussed, progress in the work took the following form.

1. It was generally agreed that the 60-cycle basis was not adequate alone for establishing insulation levels.

2. On account of the lack of a suitable agreed-upon yardstick with which to measure voltage levels, an air gap was at first considered, it being the best means available at that time. This gap initially took the form of a so-called edge gap, and later became the rather well-known rod gap, having definite limitations of spacing and physical arrangement.

3. Recognized testing laboratories of manufacturers and others were not in agreement on voltage flashover values of standard every-day types of equipment such as suspension insulators, bus supports, bushings, insulators, etc. This disagreement covered not only the field of 60-cycle voltage measurements but also that of impulse voltages. A so-called interlaboratory group was, therefore, formed to work on this problem and reach an agreement on proper values for similar apparatus. The work of this committee has been carried on carefully and persistently until at the present time the hoped-for agreement has been reached, within reasonable tolerances of measurement, on a great deal of electric equipment and on gaps. One paper has previously been published[1] giving results of this work. Also, a paper is now being presented[2] by the interlaboratory group giving agreed-upon flashover values of insulators and gaps.

A subcommittee was also appointed to investigate the existing practice of insulation of lines and equipment in the operating companies with the idea that such data would serve as a basis for setting up practical, workable, and effective levels of insulation in carrying out the first statement of principles given above.

This subcommittee spent a great deal of time and effort

**Table I. Basic Impulse Insulation Levels**

| (1) Maximum Rated Voltage Classification (Kilovolts) § | (2) Basic Impulse Insulation Level (Crest Kilovolts) # | (3) Rod Gap† Having Flashover in Column 2 (Inches) |
|---|---|---|
| 1.2 | 32 | 0.8 |
| 2.5 | 53 | 1.6 |
| 5.0 | 63 | 2.2 |
| 8.66 | 80 | 3.3 |
| 15 | 100‡ | 4.5‡ |
| 25 | 150 | 7.1 |
| 34.5 | 190 | 10.2 |
| 46 | 250 | 13.5 |
| 69 | 360 | 20.6 |
| 92 | 470 | 27.5 |
| 115 | 570 | 34.5 |
| 138 | 680 | 42.1 |
| 161 | 790 | 49.0 |
| 196 | 950 | 60.0 |
| 230 | 1,100 | 70.4 |
| 287 | 1,360 | 88 |
| 345 | 1,620 | 106 |

§ Based on "NEMA-NELA Preferred Voltage Ratings for A-C Systems and Equipment," NELA Publication Number 043, page 12, and on transformer subcommittee AIEE paper, Electrical Engineering, January 1937, page 32.

# Crest kilovolts of $1^1/_2$x40 impulse wave.

† Given for reference only. Gap spacings are those giving 50 per cent flashover and 50 per cent full wave when subjected to $1^1/_2$x40 positive impulses with crest values given in column 2 under standard conditions of air density and humidity.

‡ Consideration should be given to increasing these values approximately 10 per cent.

A paper recommended for publication by the AIEE committees on electrical machinery, protective devices, and power transmission and distribution. Manuscript submitted March 18, 1937; released for publication April 12, 1937.

* Sponsored by the lightning and insulator subcommittee of the AIEE committee on power transmission and distribution.

** Prepared by the group chairmen: Edison Electric Institute group, Philip Sporn; National Electrical Manufacturers Association group, C. A. Powel.

1. For all numbered references see list at end of paper.

in collecting and correlating these data, keeping in mind that the final levels selected must be based on practical as well as theoretical considerations. Within the last few months it finally agreed upon a set of basic impulse insulation levels utilizing as steps the preferred voltage classification adopted by NELA.[3] This series of basis impulse insulation levels adopted by the joint committee in January 1937 is presented in table I.

It will be noticed that the table gives the basic impulse levels for each "maximum rated voltage classification." In the lower range of voltages, this classification differs slightly from the preferred voltage ratings previously adopted by NEMA in the publication referred to above, but the steps given in table I are considered advisable in the light of the fact that present-day transformers in that range are specified in terms of those voltages.

It will be further noted that a fundamental and very important change has been made in this table, in that basic impulse insulation level is definitely expressed in terms of voltage. This voltage is the crest voltage of a $1^1/_2$x40 positive wave which will just cause flashover on the tail of the wave when impressed on the so-called standard rod gap having $^1/_2$-inch square-cut electrodes. The gap spacings corresponding to these voltage values are given in the third column. These rod gap spacings are given for reference only, the basic level being crest kilovolts in column 2.

## Future Work

The first step in the co-ordination of insulation has therefore been finished and the second step, *viz.*, "Specification of insulation strengths of all classes of equipment in the established insulation levels," is now ready to be undertaken. This work has actually been begun since a subcommittee of the joint committee has been appointed and is working on this part of the program.

Now that the above insulation levels have been agreed upon, it is expected that more rapid progress will be made in carrying on the work still to be done. As the work progresses, it is planned to officially release periodically to the engineering field the findings and recommendations of the joint EEI-NEMA committee on system insulation co-ordination.

## References


1. Flashover Voltages of Insulators and Gaps, committee report, AIEE Transactions, 1934, page 882.

2. Report on Flashover Characteristics of Rod Gaps and Insulators, interlaboratory group of EEI-NEMA. Electrical Engineering, volume 56, June 1937, pages 712–14.

3. NEMA-NELA Preferred Voltage Ratings for A-C Systems and Equipment, NELA Publication No. 043, page 12.


# Flashover Characteristics of Rod Gaps and Insulators


A Report by the Subcommittee* on Correlation of Laboratory Data of EEI-NEMA Joint Committee on Insulation Co-ordination**


THIS REPORT has been written to present the agreed upon impulse and 60-cycle flashover values for rod gaps and suspension line insulators, together with a method of making correction for variation in humidity. The laboratory work and correlation upon which these data are based was done by the subcommittee on correlation of laboratory data* of the joint EEI-NEMA committee on insulation co-ordination. The joint committee authorized the publication in Electrical Engineering of this work through a paper sponsored by the AIEE subcommittee on lightning and insulators. This makes the information more generally available to the the industry for use in connection with the general problem of insulation co-ordination.

## General

With the advent of impulse testing, it was immediately apparent that the flashover values given out by various laboratories for the same test piece were different. In an effort to learn the cause of this, 2 things were done; a string of suspension insulators was circulated to the Locke, Ohio Brass, and General Electric laboratories; and identical bushings were tested in the Westinghouse and General Electric laboratories. These moves, while of some benefit, did not lead to any lasting results. Then the laboratories of Westinghouse and General Electric, between whom the widest divergence in results existed, began to interchange information on testing procedure. Soon Ohio Brass joined the group, then Locke, and finally Allis-Chalmers. For a while the group was known as the "laboratory group" and later as the "EEI-NEMA subcommittee on correlation of laboratory data."

No effort will be made in reporting the work of this committee to include any supporting data—only the final results will be given and with a minimum of explanatory remarks.


A paper recommended for publication by the AIEE committees on power transmission and distribution, electrical machinery, and protective devices. Manuscript submitted February 26, 1937; released for publication April 20, 1937.



* Personnel of Edison Electric Institute-National Electrical Manufacturers Association subcommittee on correlation of laboratory data: C. A. Powel, *chairman;* J. E. Clem, *secretary;* P. H. McAuley; H. A. Frey; J. T. Lusignan; L. H. Hill; C. M. Foust; and K. B. McEachron.

** Prepared by J. E. Clem.

## Test Conditions and Method of Analysis

### Flashover Tests

Before any effort was made to agree upon flashover values for common use, the committee laid down the requirement that the test points from which the curves were obtained in any of the participating laboratories should be within plus or minus 5 per cent of the average curve of that particular laboratory. The requirement was also made that the curves of all the laboratories be within a spread of less than 5 per cent. These requirements covered both impulse and 60-cycle flashover tests.

On this basis it is reasonable to expect that the individual points in any laboratory may have an extreme variation from the average curve of plus or minus 8 per cent. Consequently, when the curves based upon the average results of all the laboratories are used for determining flashover values the tolerance of points detained in any specific laboratory from the general average curves should be plus or minus 8 per cent.

During the course of the work of the subcommittee, each laboratory developed its own type of equipment and methods for producing and measuring impulse voltages. The study of the technique of impulse testing was taken up a few years ago by a subcommittee of the AIEE instruments and measurements committee and the technique has since then become more and more standardized. The laboratory group had for its major problem the study of the factors which cause divergence in results among the various laboratories rather than a study of the details which would lead to extreme accuracy. This latter topic is more properly the work of the AIEE instruments and measurements committee.

Flashover values were obtained on both the 1x5- and 1.5x40-microsecond waves. These 2 waves are among those proposed as standard by the AIEE subcommittee on lightning and insulators. For the work on this subcommittee the first number in the wave designation was taken as indicating the time in microseconds from the virtual time zero to actual crest voltage, and the second number as indicating the time from the virtual time zero to the point on the tail of the wave where the voltage is half of the crest value. The flashover data recorded is the crest value of the minimum impulse flashover voltage (full wave) and is given for both negative and positive polarity waves.

The virtual time zero is the point of intersection with the zero voltage deflection line of a line drawn through

**Table I. Impulse Voltage Flashover—Suspension Insulators, 10-Inch Diameter, $5^3/_4$-Inch Spacing**

Barometer, 30 Inches; Temperature 77 Degrees Fahrenheit; Humidity 0.6085-Inch Vapor Pressure

Data From Allis-Chalmers, General Electric, Locke, Ohio Brass, and Westinghouse Laboratories Averaged

| Number of Units | Minimum Impulse Flashover Voltage (Kilovolts) | | | |
|---|---|---|---|---|
| | 1x5 Microsecond Wave | | 1.5x40 Microsecond Wave | |
| | Positive | Negative | Positive | Negative |
| 1 | 155 | 155 | 150 | 150 |
| 2 | 285 | 295 | 255 | 255 |
| 3 | 395 | 410 | 355 | 345 |
| 4 | 500 | 520 | 440 | 415 |
| 5 | 610 | 630 | 525 | 495 |
| 6 | 715 | 750 | 610 | 585 |
| 7 | 820 | 860 | 695 | 670 |
| 8 | 930 | 975 | 780 | 760 |
| 9 | 1,040 | 1,090 | 860 | 845 |
| 10 | 1,145 | 1,205 | 945 | 930 |
| 11 | 1,250 | 1,320 | 1,025 | 1,015 |
| 12 | 1,355 | 1,430 | 1,105 | 1,105 |
| 13 | 1,460 | | 1,185 | 1,190 |
| 14 | 1,565 | | 1,265 | 1,275 |
| 15 | 1,670 | | 1,345 | 1,360 |
| 16 | 1,775 | | 1,425 | 1,445 |
| 17 | 1,880 | | 1,505 | 1,530 |
| 18 | 1,985 | | 1,585 | 1,615 |
| 19 | 2,090 | | 1,665 | 1,700 |
| 20 | 2,200 | | 1,745 | 1,785 |

**Tolerances**

These values represent average results of tests on suspension line insulators of different design and manufacture made in different laboratories. When tests are made in any particular laboratory upon an insulator unit or assembly of specific design and manufacture, the flashover should be within plus or minus 8 per cent of the value given in the tabulation.

In accordance with AIEE Standards No. 41, the comparison should be made on the basis of the average flashover obtained from tests on 3 separate insulator units or assemblies.

Note: Negative wave flashovers are inherently more erratic than positive wave flashovers resulting in a greater chance of the tolerances being exceeded occasionally.

**Table II. Impulse Voltage Flashover—Rod Gap**

Barometer, 30 Inches; Temperature, 77 Degrees Fahrenheit; Humidity, 0.6085-Inch Vapor Pressure

Data From Allis-Chalmers, General Electric, Locke, Ohio Brass, and Westinghouse Laboratories Averaged

| Gap Spacing (Inches) | Minimum Impulse Flashover Voltage in Kilovolts | | | |
|---|---|---|---|---|
| | 1x5 Microsecond Wave | | 1.5x40 Microsecond Wave | |
| | Positive | Negative | Positive | Negative |
| 0.5 | 22 | 23 | 22 | 23 |
| 0.75 | 30 | | 30 | |
| 1.0 | 38 | 38 | 38 | 38 |
| 1.5 | 51 | 51 | 51 | 51 |
| 2 | 60 | 62 | 60 | 62 |
| 3 | 76 | 83 | 75 | 82 |
| 4 | 97 | 103 | 91–95* | 102 |
| 5 | 120 | 124 | 106–114 | 123 |
| 6 | 143 | 146 | 128–141 | 143 |
| 7 | | 167 | 141–155 | 163 |
| 8 | 187 | 188 | 159–166 | 183 |
| 9 | | 209 | 175–178 | 203 |
| 10 | 233 | 231 | 190 | 224 |
| 12 | | 273 | | 259–271 |
| 14 | | 315 | | 293–318 |
| 15 | 340 | 335 | 275 | 309–342 |
| 16 | | 360 | | 323-359 |
| 18 | | 400 | | 360–386 |
| 20 | 440 | 445 | 350 | 395 415 |
| 25 | | 550 | | 490 |
| 30 | 640 | 660 | 505 | 575 |
| 40 | 835 | 875 | 650 | 740 |
| 50 | 1,035 | 1,085 | 800 | 910 |
| 60 | 1,230 | 1,300 | 945 | 1,070 |
| 70 | 1,425 | 1,515 | 1,095 | 1,235 |
| 80 | 1,620 | | 1,240 | 1,405 |
| 90 | 1,815 | | 1,385 | 1,570 |
| 100 | 2,010 | | 1,530 | |

* Dual values are due to unstable conditions the cause not being known.

**Tolerances**

These values represent average results of tests made in different laboratories. When tests are made in any particular laboratory using the rod gap as a basis of comparison the flashover voltage shall be taken from the above tabulation and shall be considered as correct within plus or minus 8 per cent.

Note: Negative wave flashovers are inherently more erratic than positive wave flashovers resulting in a greater chance of the tolerances being exceeded occasionally.

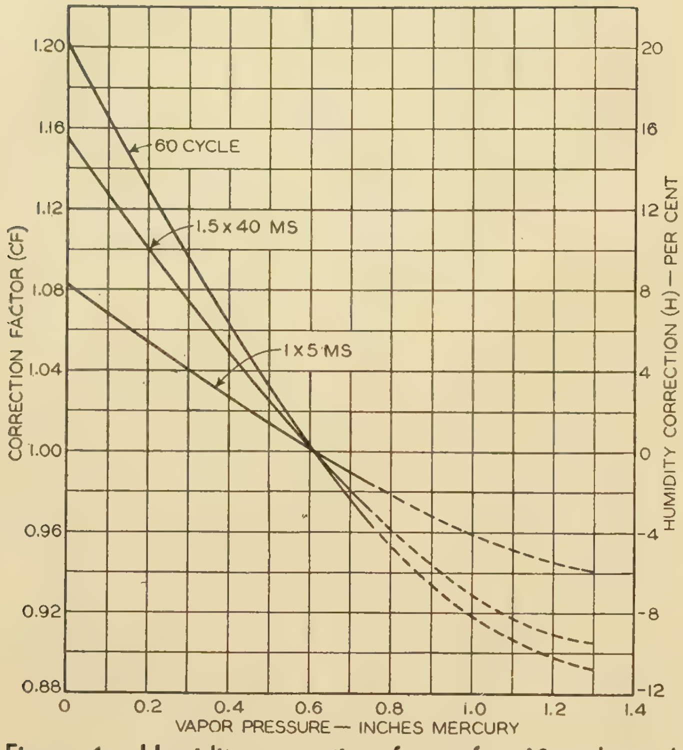



**Figure 1. Humidity correction factor for 60-cycle and positive-wave impulse flashover of rod gap and suspension line insulators**

For humidities 0.75 inch and above the correction is less reliable on account of the erratic data from which the correction was determined

Curve values apply to flashover voltages above 141-kv crest. For lower flashover voltages reduce H in proportion H′ = H kv/140

points on the front of the wave at 10 per cent and 90 per cent of the crest voltage deflection.

All 60-cycle tests were made in accordance with the rules of the AIEE.

Voltage measurements were made in some cases by means of sphere gaps and in other cases by means of the cathode-ray oscillograph. The flashover values given are all based on the revised sphere gap calibrations given in the report of the AIEE subcommittee of the instruments and measurements committee, and published on page 783 of the July 1936 issue of Electrical Engineering.

## Humidity Effects

Data on the effect of variations of humidity on the flashover have been analyzed and correction factors developed. The flashover data for each insulator assembly and gap spacing were plotted against the recorded humidity and the flashover voltage determined for the standard vapor pressure. This reference value was then used as the base for determining individual correction factors for the test points. The curves of correction factors thus obtained for various insulator assemblies and gap spacings were combined and the most probable average curve determined. The accuracy of the data did not support any differentiation between the correction factor for rod gaps and insulators at the present time.

It should be noted that there is a wide variation of the points in some cases, especially for the higher values of humidity. Accordingly, it is highly possible that some inconsistencies may be encountered when flashover tests are made at high humidities.

## Results

### Flashover Data

The average flashover voltages agreed upon for insulators and rod gaps are given in tables I, II, and III. In the opinion of the committee these values are sufficiently accurate to warrant their use for co-ordination purpose and are recommended for use until such time as sufficient additional data are obtained to confirm or modify them.

### Humidity Correction

The curves showing the correction factors to be used for variation in humidity are shown in figure 1. The correction is given in 2 forms: As a "correction factor" by which the observed flashover is to be multiplied; and as a "humidity correction" which is the percentage to be added to or subtracted from the observed flashover.

**Table III. 60-Cycle Voltage Flashover—Suspension Insulators, 10-Inch Diameter, $5^3/_4$-Inch Spacing, and Rod Gaps**

Barometer, 30 Inches; Temperature, 77 Degrees Fahrenheit; Humidity, 0.6085-Inch Vapor Pressure
Data From Allis-Chalmers, General Electric, Locke, Ohio Brass, and Westinghouse Laboratories Averaged

| Suspension Insulators | | Rod Gaps | |
|---|---|---|---|
| Number of Units | Flashover Voltage (Effective Kilovolts) | Gap Spacing (Inches) | Flashover Voltage (Effective Kilovolts) |
| 1 | 80 | 0.5 | 11.5 |
| 2 | 155 | 0.75 | 17.5 |
| 3 | 215 | 1 | 22.5 |
| 4 | 270 | 1.5 | 32 |
| 5 | 325 | 2 | 40 |
| 6 | 380 | 3 | 50 |
| 7 | 435 | 4 | 58 |
| 8 | 485 | 5 | 66 |
| 9 | 540 | 6 | 74 |
| 10 | 590 | 8 | 89 |
| 11 | 640 | 10 | 105 |
| 12 | 690 | 15 | 150 |
| 13 | 735 | 20 | 200 |
| 14 | 785 | 30 | 295 |
| 15 | 830 | 40 | 385 |
| 16 | 875 | 50 | 480 |
| 17 | 920 | 60 | 575 |
| 18 | 965 | 70 | 665 |
| | | 80 | 755 |
| | | 90 | 835 |

**Tolerances**

Suspension Insulators

These values represent average results of tests on suspension line insulators of different design and manufacture made in different laboratories. When tests are made in any particular laboratory upon an insulator unit or assembly of specific design or manufacture, the flashover should be within plus or minus 8 per cent of the value given in the tabulation. In accordance with AIEE Standards No. 41, the comparison should be made on the basis of the average flashover obtained from tests on 3 separate insulator units or assemblies.

Rod Gaps

These values represent the result of tests on rod gaps made in different laboratories. When tests are made in any particular laboratory using the rod gap as a basis of comparison, the flashover voltage shall be taken from the above tabulation and shall be considered as correct within plus or minus 8 per cent.

It should be noted that the sphere gap is the standard for voltage measurements and that the rod gap is to be used only when approximate results will be satisfactory.

# Insulation Co-ordination

By PHILIP SPORN
FELLOW AIEE

I. W. GROSS
ASSOCIATE AIEE

## I. Introduction

THIS SUBJECT of insulation co-ordination has been an active one for the past 10 years or so. It was initially presented and discussed in 1928.[1] Since then, the subject was taken up by practically all groups interested in the transmission problem including designers and operators of electric systems. As the study of the problem gathered headway, the need for further investigation work became quickly apparent. A great number of individual researches were thus started. All of them although closely related were not entirely co-ordinated. Each of them, however, in its own way, arrived at a solution of all, or of a part of the problem of co-ordinating the insulation strength of the electric system.

Such investigation and research work included[2–15] field investigation of lightning on transmission lines, determination of system overvoltages, experience in actual practice, collection and analysis of operating records of apparatus and system performance. In the laboratory, a great deal of work was also done in determining the insulation strength of various pieces of apparatus and equipment. Included in this work was a determination of transformer safe impulse strength, flashover characteristics of insulators, gaps, and some work, still incomplete, on impulse strength of switch insulators and bushings.

## II. Objective of Insulation Co-ordination

All of this work, the scope and inter-relationship of which is daily becoming closer, has as its goal, insulation co-ordination.

Insulation co-ordination has 2 main objectives: (1) protection of service and equipment, and (2) economy. Strictly speaking, however, these 2 objectives merge into one—economy. This is true of every problem in protection. In the case of insulation co-ordination, what is aimed at is an electric system so insulated in its various parts and such an arrangement in the insulation strengths of the various parts as regards one another that under all conditions the grade of service aimed at is obtained at a minimum cost. In the item of cost, there must be included, of necessity, fixed charges on first cost of equipment, cost of damages, cost of outages, cost of spare equipment, and cost or value of decrement or increment in good will.

## III. More Detailed Statement of the Co-ordination Problem

As stated above, insulation co-ordination from a very broad standpoint becomes an economic problem. That, however, is not adequate for a thorough analysis of the problem. For in any such analysis it must be recognized that what one is generally confronted with in a physical plane is insulation strength or insulation failure, both in the right and in the wrong places.

Now insulation strength raises the question of overvoltages. These overvoltages may be divided into 3 groups:

First: Those due to 60-cycle or normal frequency

Second: Those due to switching surges

Third: Those due to lightning

In the past, 60-cycle overvoltages have, in general, not been the subject of any grave concern and we can view the standard overvoltage test of equipment as a safe criterion to use in selecting insulation on a normal frequency basis alone. However, the fact that apparatus designed, tested, and used on the standard double-voltage test has given satisfactory service should not blind us to the possibility that a less severe 60-cycle test would have given equally satisfactory results. If this should prove to be true, it is obvious that insulation can be reduced from the past standards even on a 60-cycle basis with considerable economic gain and without any loss of reliability of service.

The second type of voltage to be protected against is the switching surge. Here, our basic knowledge on switching surges, both as regards the characteristics of such surges and the ability of insulation to withstand them,[15,16] needs enlargement. However, troubles from this source have not been frequent. But switching surges can by no means be overlooked in setting up insulation levels and carrying through any plan of co-ordination.

The third type of overvoltage is the one which has been given most consideration during the past decade, namely, lightning voltages, and it is around this phase that insulation co-ordination problem now largely centers.

The insulation used to furnish protection against these overvoltages must of necessity be of the same material as that used to supply the insulation against the *normal* 60-cycle voltages, that is, it must consist of additional oil, fiber, air, or porcelain. The only problem is how far to go if that method of avoiding trouble is chosen. The general principle of overinsulation, that is, adding insulation above past accepted standards has not proved very successful. Where it has been resorted to in the past and has not resulted in the mere transferring of the

---

A paper recommended for publication by the AIEE committees on protective devices and electrical machinery. Manuscript submitted March 26, 1937; released for publication April 12, 1937.

PHILIP SPORN is vice-president and chief engineer of the American Gas and Electric Company, New York, N. Y. I. W. GROSS is electrical research engineer with the same company.

1. For all numbered references see list at end of paper.

trouble to some other point in the system, it has invariably been at heavy economic expense. The alternative to additional insulation is a group of protective devices such as gaps, lightning arresters, etc. It is unfortunate that, although a great deal of practice has concentrated in that line, altogether too little has been known about most such devices as lightning arresters and gaps. Some of the more recent work on insulation co-ordination has clearly brought this out.

In any event, regardless of whether adequate insulation alone or overinsulation alone is used, or protective devices alone, or a combination of these is employed, it is apparent, as was initially[1] clearly shown that insulation levels must be set up for all the different groups of apparatus, with proper grading between all the links in every insulation chain at any particular level, and satisfactory margin of safety supplied at each of the levels.

## IV. Information Needed

In setting up such insulation levels, there are several essential requirements: First, the expected magnitude and characteristics of overvoltages must be known with some degree of certainty; this applies not only to lightning voltages but also to 60-cycle and switching surge voltages. Coupled with this, information on the safe insulation strength of apparatus must be available. Finally, the voltage protective characteristics of the protective devices used under operating conditions must be known with a reasonable degree of certainty.

In this connection an important factor which has received very little attention is the question of margins at the various insulation levels which are finally adopted between equipment and protective device. For example, if a transformer will withstand, safely, an impulse voltage of, say, 600 kv, the question must be asked as to how much margin should be allowed between the transformer and the protective device to insure that the protective device will prevent excessive voltage on the transformer. The same consideration must obviously be given to other pieces of equipment on a system, such as bushings, bus insulators, instrument transformers, etc. The correctness of such margins as adopted will eventually have to be tried out and proved under operating conditions.

As information of this kind is obtained and correlated, it will eventually make possible a scientifically sound co-ordinated system of insulation levels for the various operating voltages with proper margins or steps for every insulation level between the different component parts of the transmission system, such, for example, as between the transformer and the switch insulators, between the switch insulators and the bus, and between other similar links in the insulation chain.

## V. Progress to Date

In reviewing some of the work which has been done to date, the following points are of interest as indicative of the progress made in insulation co-ordination: First, 60-cycle strengths are pretty well known for transformers, bushings, suspension insulators, pedestal insulators, gaps, etc. Second, some work has been done in obtaining magnitude of switching surges and data on the ability of insulation to withstand them. Third, and this is probably the most important, impulse strength of many of the most important items of high-voltage equipment has been determined with some degree of certainty. Thus transformers are now being commercially impulse-tested; information is available on impulse strength of transformer bushings; the characteristics of the lightning arrester which, in the past, was a semi-mysterious protecting device, are much better understood and the protective ability of the arrester fairly well known under an ever-increasing number of operating conditions. Also, a great deal of work has been done in determining the impulse characteristics of gaps under surge conditions. In this connection, it is pertinent to point out that the recognized impulse laboratories today have so improved and perfected their technique that they are now almost universally operating on a basis where comparable data can be obtained.

While much data have been obtained, and are being obtained, on impulse characteristics of insulation, the main problem of utilizing these data effectively in insulation co-ordination has not progressed as rapidly. This however, is natural in view of the fact that a practical and workable system of co-ordination must await the time when information is available on the insulation strengths of all the apparatus concerned and accurate knowledge of the impulse characteristics of the protective devices employed. Fortunately, however, a great deal of the fundamental data are now available and insulation co-ordination is beginning to take form. Only recently, as reported in the companion paper, basic insulation levels for the preferred voltage ratings have been adopted. This will undoubtedly serve as a stimulus to the more active pursuit of the work needed to bring about co-ordination. But it must not be forgotten that the entire problem of correlating the laboratory test data, the field data, and various ideas and theories of electrical system design into a practical, workable system of insulation and protective levels still remains to be done.

## Insulation Co-ordination Chart

So many different groups have been working on this subject each within its own field that it is believed that it will be helpful to present a rather complete picture of the insulation strength of major equipment and protection available. With this thought in mind, the authors have collected and correlated a great deal of the available data on the subject and have prepared it in graph form. This is shown in the insulation co-ordination chart, figure 1. It is presented as an accumulation of data bearing on the insulation problem which in their own work the authors have found useful time and again to get and keep an over-all picture of the insulation problem in all voltage classes from 1 kv to one step beyond the present range of operating voltages, namely, 347 kv.

On this chart there have been plotted, in the upper left-

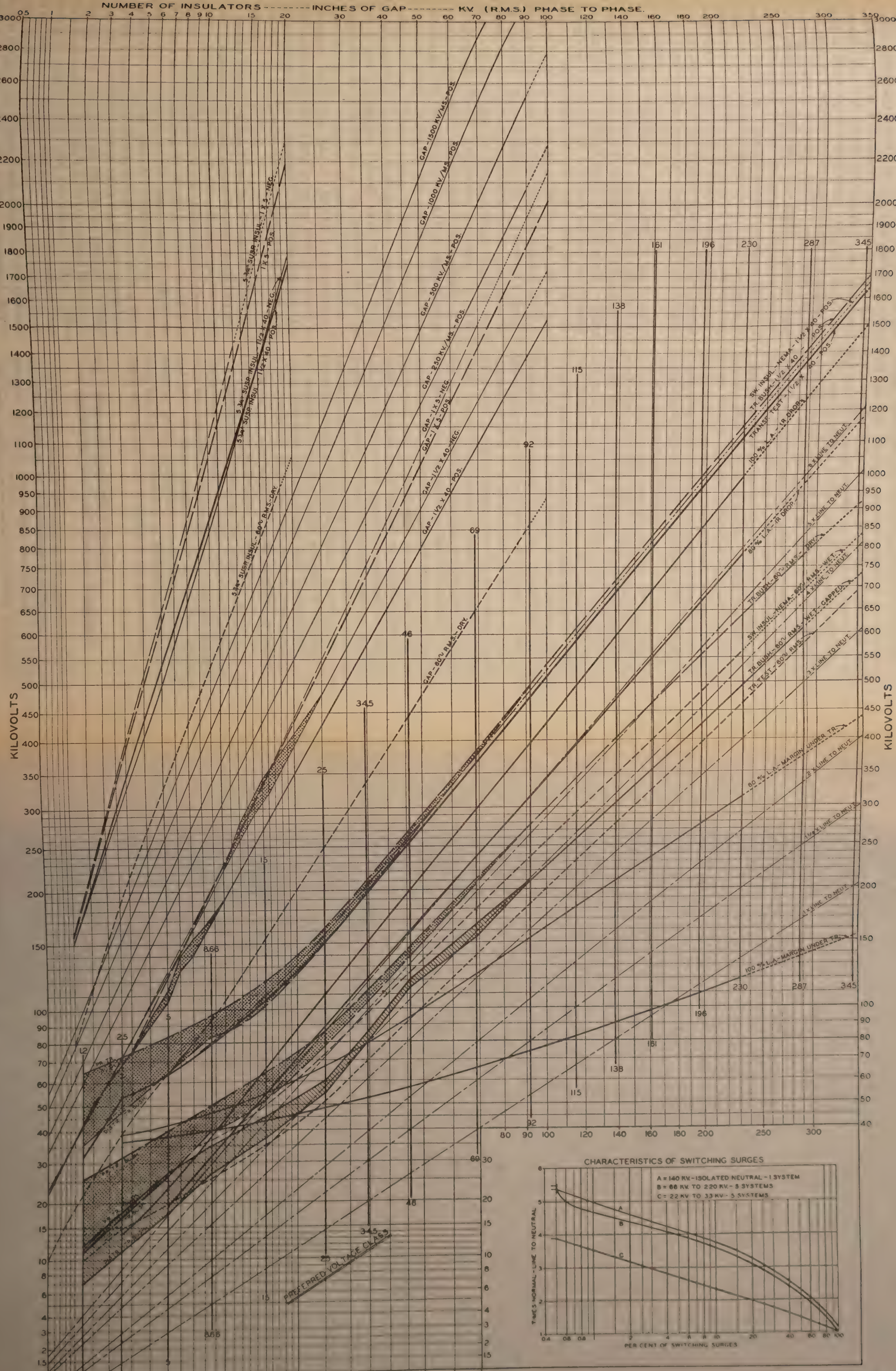



Figure 1

*Sporn, Gross—Insulation Co-ordination*

hand corner, the impulse characteristics, both positive and negative, and 60-cycle flashover values of suspension insulators from 1 to 20. Flashover characteristics of the rod gap, which has been extensively used during the past number of years as a measuring and test device for co-ordinating the work of the laboratories, are shown immediately below the insulator data. In the lower right-hand corner is a graphic presentation of the magnitude of switching surges as actually observed from field studies under operating conditions. The major group of lines running diagonally through the center of the chart represents the insulation characteristics of various pieces of equipment, and lightning arresters and also multiples of system line to neutral voltages. For easy identification, the preferred voltage class of insulation is shown by vertical lines located at the proper spacing as determined by the phase-to-phase system voltage scale at the bottom of the chart.

By the use of the chart it is possible to get a rather complete over-all picture of the insulation situation in any voltage class by merely following a vertical line marked with the preferred voltage class: For example, reading values from the chart, on a 138-kv system the impulse test on transformers would be 680 kv, the impulse flashover of the bushing 720 kv. A 100 per cent arrester would have an *IR* drop, at 5,000 amperes through the arrester of approximately 600 kv, leaving a margin between the arrester and the transformer of approximately 90 kv. To determine the test gap which would be used in testing the 138-kv transformer according to AIEE transformer standards, merely trace horizontally from the intersection of the 138-kv vertical line with the transformer test (diagonal line) to the gap curve which shows a $42^1/_2$-inch gap. Such a gap, however (tracing vertically upward) would have a flashover of approximately 770 kv with a negative $1^1/_2$x40 wave, 925 kv with a 1x5 negative wave, 1,290 kv if the impulse rose at the rate of 500 kv per microsecond positive, and 1,600 kv if the impulse rose at the rate of 1,000 kv per microsecond. It is obvious that such a gap furnishes little protection to the transformer under impulse if it is assumed that the test value of the transformer is approximately its safe strength.

Another interesting point can be determined from this chart. Again start at the intersection of the 138-kv preferred voltage class line with the transformer test curve and go horizontally to the gap curve for 1,000 kv per microsecond. It is observed that a gap set at $16^1/_2$ inches would flash over at 690 kv, that is, at the same value at which the transformer would be tested. Following down to the 60-cycle gap flashover curve, it is seen that such a $16^1/_2$-inch gap would flash over at 165 kv and again going horizontally from this point to the 138-kv preferred voltage class line it appears that such a voltage would be approximately 2.1 times normal line to neutral voltage. Thus a gap which will limit a steep wave front positive surge in order of 1,000 kv per microsecond to the tested transformer strength would have such a low 60-cycle flashover that it would undoubtedly result in increased service outages under overswitching surge conditions.*

In applying lightning arresters for protection there should, of course, be some margin between the terminal voltage of the arrester under impulse conditions and the safe strength of the apparatus which it is to protect. This margin has been shown near the bottom of the chart for the 100 per cent arrester, as a full line curve. It will be noted that this margin varies from approximately 35 kv in the 2,500-volt class to 120 kv at an operating voltage of 230 kv. This gives an idea of the general range of margins which have been possible in recent years. A curve slightly higher up is also drawn showing the impulse characteristics of an 80 per cent lightning arrester. The so-called 80 per cent arrester is taken as one having 80 per cent of the active material of a 100 per cent arrester and in general is considered suitable for use only on a grounded neutral system of normal rating or on an isolated neutral system rated 80 per cent of the conventional 100 per cent arrester voltage.

Reverting to the example of the 138-kv insulation cited above, it will be noted that a 100 per cent arrester would not supply any protection for a transformer in the 115-kv class. However, if an 80 per cent arrester were used there is a margin between the arrester and 115-kv class of transformer insulation of approximately 110 kv. This 80 per cent arrester, however, has little margin for a standard 92-kv transformer, the transformer test and lightning arrester *IR* drop being about equal. Thus, it is apparent that if it is deemed safe to use an 80 per cent arrester on a 132-kv system (and this is entirely feasible where the 60-cycle voltage is limited by system grounding, etc.) it is possible, from the impulse protection point of view, to use insulation in the 115-kv class. If it is possible to cut the arrester to below 80 per cent it may be possible to use a transformer even in the 92-kv class without decreasing the margin of safety appreciably below that used in the past with standard 100 per cent arresters. Cases of this kind where reduced insulation has been used on our own system with a substantial economic saving will be cited below. In every case careful analysis shows that ample margins of insulation remained between the transformer and arrester levels.

It is believed that this chart will be found useful in analyzing in a general way with considerable accuracy many problems of the above character.

It should be pointed out that some of the data in the above chart are subject to further check and confirmation, such, for example, as impulse flashover of switch insulators and the *IR* drop characteristics of modern lightning arresters under present-day conditions. All data, however, have been collected from sources believed to be reliable and are the best available at the present time.

## VI. Present Insulation Practice of American Gas and Electric Company

In the work on their own system the authors have been using the principles of co-ordination over the past 10 years. Initially the basic idea sought was to have the various

* This, however, does not take into account the possibilities of ultrahigh-speed breaker reclosure.

component parts of the transmission system properly insulated with regard to each other and all properly insulated for the operating voltage and conditions encountered. But as they progressed in their work and in thinking out the problem, the ideas of co-ordination began to offer more and more means of reducing intelligently the cost of transmission equipment. Some 5 years ago, therefore, the authors first went thoroughly into the insulation problem presented by a 132-kv transformer installation and, as a result, placed in service a reduced insulation transformer, that is, one with insulation lower than normal for the system rating. As a matter of fact, they actually used 115-kv insulation on a grounded-neutral 132-kv system. Several very similar installations involving large 132-kv transformer banks have been placed in service on their system during the past year and others are being added. A comparison of the insulation co-ordination of such a transformer with some of the other links in the insulation chain in the station is shown in figure 2. It will be noted that on an impulse basis, the transformer tested strength is approximately 40 per cent above the lightning arrester *IR* drop. It will also be noted that the switch insulators have an impulse strength some 5 per cent above the transformer strength and the bus some 50 per cent above the switches. The transformer bushings were gapped, according to present transformer practice, at 5 per cent above the transformer test. In this connection, however, it may be well to point out that the practice of gapping transformer bushings in service to the 5 per cent margin above the transformer test recommended by the transformer subcommittee has been recently discontinued by the authors.

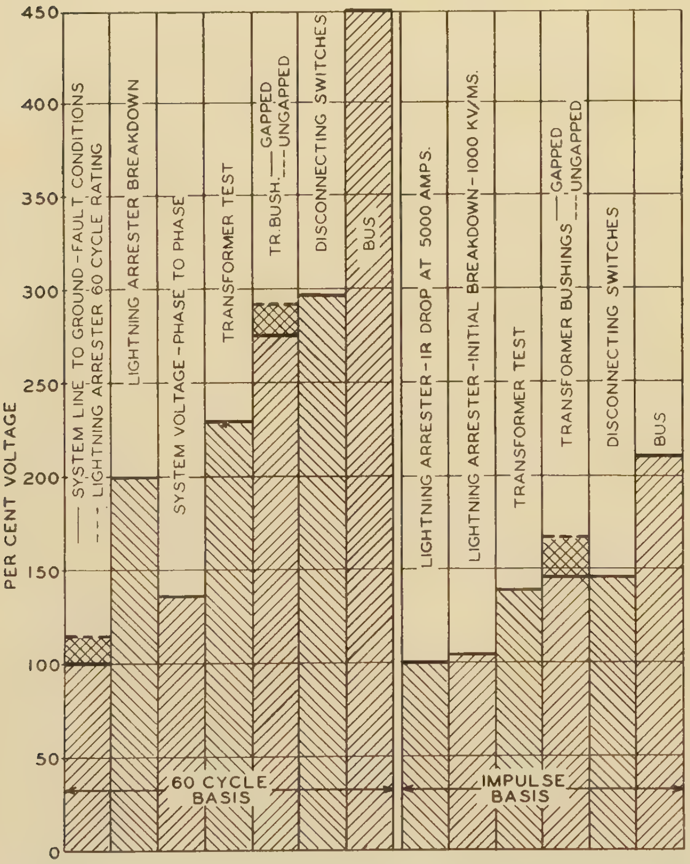



**Figure 2. Insulation co-ordination on grounded-neutral 132-kv system of American Gas & Electric Company (installation in 1936)**

There are 3 reasons for doing this: First, the impulse characteristics of the transformer bushing, with gap spacings recommended, does not indicate that protection will be afforded the transformer on steep wave fronts; second, if the gap on the bushing flashes over there is almost sure to be sufficient damage to the bushing so that extensive repairs have to be made, in many cases, not only to the bushing itself but to other bushings. Two cases of this kind have been experienced in the last year on gapped bushings. Third, transformer bushings in the lower voltage class, if gapped, have such small mechanical clearance that these gapped bushings become hazards in a major substation instead of safety devices.

It will be noted also in figure 2 that the bus insulators, both impulse and 60-cycle, are placed well above any other equipment in the station. This policy the authors have consistently followed on the basis that any damage to the bus structure may involve service interruptions sometimes that will affect a larger area of service than damage to any other piece of equipment of embarrassing durations.

## Selecting Transformer Insulation

In selecting reduced insulation for large-size high-voltage transformers, the procedure followed by the authors within the past year has been as follows:

1. The overvoltages on a system, due to faults or other effects, such as hydro, are calculated and on this basis a suitable arrester is selected adequate to stand up in service under the worst 60-cycle voltage conditions.
2. The impulse characteristics of this arrester are determined.
3. The transformer impulse strength is placed at a margin considered safe above the lightning arrester voltage and the class of insulation into which that transformer falls is then selected.

In other words, the start is with the lightning arrester as a protective level; the necessary margin between the arrester and the transformer is then set, and then the transformer insulation level is picked. As mentioned above, this has resulted on the authors' system in the selection during the past year of several large-sized transformers with 115-kv class insulation for 138-kv class of service. There has even been considered in one case, so far, and it is believed feasible, to use so-called 92-kv class insulation for 138-kv service where 60-cycle voltage conditions are favorable.

This plan of so-called reduced insulation not only results in economic savings in the initial cost of the transformer, but also gives added protection to other equipment in the station by holding the impulse level low with a low-rated arrester. In view of the fact that the authors of late have gone extensively into the practice of locating lightning arresters directly on the transformer and are

gradually removing them from the lines at the line entrance, greater protection will be supplied the entire station by the reduced-rated arrester than would be possible with the so-called 100 per cent arrester. Thus, the initial reduction of transformer insulation to a lower voltage class has resulted not only in a more economical transformer but greater protection for the entire station concerned.

### Bus and Switching Insulation Practice

In tables I and II are given 60-cycle and impulse voltage characteristics of the present standards which are being used for switches and insulators in station design on the authors' system. A comparison is made in these tables with values recommended by National Electrical Manufacturers Association. It will be noted that the authors' practice calls for flashover values, both 60-cycle and impulse, except for post-type insulators in the 132-kv class, which are higher than NEMA recommendations. While it may be possible to use insulation with lower flashover than the authors' indicated practice, it should be kept in mind that bus insulators are only a small portion of the cost of the total station equipment, and the steps in insulation from one insulator to another are so large that it is not usually feasible to hew closely to a given minimum insulation value. Further, the bus is one part of the system that it is well to protect against flashover under any condition, leaving the more finely graded steps of insulation to be worked out for the other links of equipment and apparatus in the station.

It will be noted that there is one outstanding case where the authors' insulation practice is below a NEMA recommendation, and that is for post-type insulators in the 132-kv class where the impulse strength is about 15 per cent below NEMA recommendation. It should be pointed out, however, that in practically all of the cases where these are used there exists lightning arrester protection designed to hold impulse voltages down below the bus insulator level. It is interesting to note, in this connection, that this lower insulation which has been used in some 35 stations on their 132-kv system, has according to their records, some of which go back 20 years, never resulted in a major case of trouble.

## VII. Work Still to Be Done

As pointed out in the early part of the paper, a great deal of work has been done in obtaining fundamental data on the characteristics of insulated equipment and protective devices. The work of correlating these data and setting up workable insulation systems has been in progress for the past few years. Further and fairly rapid progress may be expected in the next 2 years. But it needs to be stressed that whatever co-ordination system may be set up, it is bound to be, in part at least, based on theory, and to that extent it must receive its final test in field experience.

The authors have outlined above, in a rather general way, some of the practices which they have adopted as a result of their work on the problem and on which we are now getting their field trials. There have also been outlined some of the methods which they have employed in arriving at the various insulation steps which they have employed in their more recent design work, and it is hoped that some of the work described above, the basis on which it was arrived, and the data used, may be useful to others who are now working on this problem. The authors look forward with confidence to the not too distant future when a group of insulation levels will have been set up, with all links of the insulation chain specified in magnitude, and with workable margins between links properly applied.

There is one final point which needs to be stressed in connection with this work of insulation co-ordination and that relates to equipment now in service which was designed and built with very little, if any, consideration given to its impulse strength. A great deal of such equipment is now in service and will of necessity have to remain so for many years to come. The problem of co-ordinating and protecting this insulation is one which will assume considerable importance in the future, particularly when the equipment becomes older. It is believed, however, that as progress is made in the simpler problem of insulation co-ordination on new equipment, the prin-

**Table I. Bus and Switch Insulation Practice—Post Type Insulators**

| Nominal Operating Kilovolts | 60-Cycle Flashover (Kilovolts) A. G. & E. Co. Dry | A. G. & E. Co. Wet | NEMA Dry | NEMA Wet | Impulse 1½x40 Positive* (Kilovolts) A.G. & E. Co. | NEMA |
|---|---|---|---|---|---|---|
| 4 | 85 | 50 | 55 | 35 | 105 | 74 |
| 6.9 | 100 | 70 | 75 | 50 | 145 | 105 |
| 12 | 100 | 70 | 75 | 50 | 145 | 250 |
| 15 | 100 | 70 | 75 | 50 | 145 | 250 |
| 22 | 140 | 100 | 95 | 70 | 210 | 145 |
| 27 | 150 | 115 | 125 | 100 | 240 | 210 |
| 33 | 150 | 115 | 125 | 100 | 240 | 210 |
| 44 | 195 | 145 | 155 | 125 | 300 | 260 |
| 66 | 300 | 235 | 220 | 180 | 500 | 380 |
| 88 | 390 | 290 | 295 | 240† | 610 | 500 |
| 132 | 385 | 285 | 400 | 350 | 620 | 735 |

* Based on some available data and ratio of impulse to 60-cycle values.
† No NEMA rating—value calculated.

**Table II. Bus Insulation Practice—Suspension Insulators**

| Nominal Operating Kilovolts | 60-Cycle Flashover (Kilovolts) A. G. & E. Co. Dry | Wet | Impulse 1½x40 Positive (Kilovolts) |
|---|---|---|---|
| 4 | 80 | 50 | 125 |
| 6.9 | 135 | 90 | 210 |
| 12 | 135 | 90 | 210 |
| 15 | 135 | 90 | 210 |
| 22 | 195 | 135 | 295 |
| 27 | 235 | 175 | 365 |
| 33 | 235 | 175 | 365 |
| 44 | 280 | 215 | 435 |
| 66 | 330 | 255 | 505 |
| 88 | 420 | 330 | 650 |
| 132 | 550 | 437 | 910 |

ciples and practices arrived at will be helpful in setting up protective measures for older equipment as well.

## References


1. Rationalization of Transmission System Insulation Strength, Philip Sporn. AIEE Transactions, 1928.

2. Surge Characteristics of Insulators and Gaps, J. J. Torok. AIEE Transactions, 1930.

3. Co-ordination of Line and Transformer Insulation, V. M. Montsinger and W. M. Dann. AIEE Transactions, 1932.

4. Lightning, F. W. Peek, Jr. AIEE Transactions, 1929.

5. Relation Between Transmission Line Insulation and Transformer Insulation, W. W. Lewis. AIEE Transactions, 1928.

6. The Effect of Transient Voltages on Dielectrics—IV, F. W. Peek, Jr. AIEE Transactions, 1930.

7. Recommendations for Impulse Voltage Testing, committee report. AIEE Transactions, 1933.

8. Co-ordination of Insulation, V. M. Montsinger, W. L. Lloyd, Jr., and J. E. Clem. AIEE Transactions, 1933.

9. Factors Influencing the Insulation Co-ordination of Transformers, F. J. Vogel. AIEE Transactions, 1933.

10. Progress Report on Impulse Testing of Commercial Transformers, F. J. Vogel and V. M. Montsinger. AIEE Transactions, 1933.

11. Rationalization of Transmission Line Insulation Strength—II, Philip Sporn. AIEE Transactions, 1930.

12. Rationalization of Station Insulating Structures, etc., C. L. Fortescue. AIEE Transactions, 1930.

13. Co-ordination session at Toronto, 1930; 7 papers. AIEE Transactions, 1930.

14. Short Time Spark-Over of Gaps, J. H. Hagenguth. Electrical Engineering, January 1937, page 67.

15. Breakdown Curve of Solid Insulators, V. M. Montsinger. AIEE Transactions 1935, page 1300.

16. Dielectric Strength of Transformer Insulation, P. L. Bellaschi and W. L. Teague. Electrical Engineering, January 1937, page 164.


---

# Fire Precautions in Electrical Stations

THE PAPER "Fire Precautions in Major Electrical Stations" by F. C. Winfield (A'22) chief electrical engineer, Merz & McClellan, Newcastle-on-Tyne, England, was presented recently in London before The Institution of Electrical Engineers. In this 10-page paper, which has 5 illustrations, the fact is observed that while electrical duplication or multiplication of equipment is recognized as essential, its complement—true physical segregation of duplicates to secure against the fire or explosion risk—has not received as much attention. However, it is emphasized that the rare occurrence of serious fires, a condition secured by the use of sound plant and good protective gear, justifies a different treatment. It is stated that "the eggs shall not be carried in one basket"; however, the conditions do not require that each "egg" be carried in a separate basket. A single clear division of plant into 2 parts is frequently sufficient. The "unit principle" of electrical arrangements, which means that each major item of equipment is provided with its own separate and distinct control and auxiliary equipment, is favored by the author.

The governing principles in fire considerations may be enumerated in 3 classes:

1. *Provisions which always ought to be made:* (*a*) the use of switchgear and plant of adequate capacity, soundly designed and constructed and provided with suitable automatic protective arrangements; (*b*) the complete electrical and fire sectioning into at least 2 duplicate parts of the switchgear, transformers, cables, etc., supplying an electric system or independent portion of a system; (*c*) minimum arrangements for fire fighting; (*d*) heating of buildings to reduce risks of insulation failures.

2. *Provisions that are easy and inexpensive to make and that reduce the spread of fire or consequential damage within a fire section:* (*a*) sealing of holes in floors or internal parts of any single fire section that has natural structural barriers; (*b*) the elimination of combustible matter not inherent to plant.

3. *Provisions that while not essential are desirable and should be applied where the importance or special conditions of the station justify the expenditure:* (*a*) floor drainage to remove oil quickly; (*b*) permanent and local fire-extinguishing plant either automatic or remote-controlled if the station is permanently attended.

An important factor in any oil-fire fighting arrangement is the dense black smoke which impedes or prohibits access to the seat of the fire. This is a most serious consideration in dealing with fires which occur in the inner regions of large power stations, for example, and for this reason it is strongly recommended that where possible, and except where small-size plant only is in question, all large transformers or switchgear should be mounted in separate buildings or in chambers opening to the outer air and sealed off from the inner side. Where this is not possible, automatic or remote-controlled forms of fire attack should always be employed, to make immediate attack on the fire without actual access being necessary.

A second important matter in all electrical failures is to eliminate the electrical contribution to the fire as rapidly as possible by tripping the switches connected to the affected bus bars and the corresponding remote feeder switches. If a sound basis can be found for doing this automatically so much to the good, but in any case operating instructions ought to provide for immediate action of this type, starting with the section switches, whenever a fire or explosion occurs.

Since prevention is better than cure, routine testing of insulation to find possible sources of failure that might cause fire is desirable. Unfortunately, no form of routine insulation testing has yet been devised which has not important objections. The so-called Doble method of testing, which makes routine field tests of watts loss and power factor with a specially portable apparatus and compares these one against another and all against continuous records of past testing, has shown promising results although there are at present certain physical limitations in its application to metalclad switch equipments.

Despite all precautions, fire cannot be absolutely precluded and the only ultimate safeguard must be a reasonable fire-sectioning of the plant, so that a fire or explosion is limited in its worst effect to a section or group of plant items which can in emergency be done without. Distinct buildings are to be preferred to barrier walls to reduce the possibility of damage by explosions, and it is suggested that one wall of structures have adequate windows or doors secured lightly so that a relief vent will be provided to reduce the force of explosions. Because of the rarity of serious fires, the actual loss sustained in damaged equipment or buildings is not of importance.

# A New High-Speed Cathode-Ray Oscillograph

By H. P. KUEHNI
ASSOCIATE AIEE

SIMON RAMO
ASSOCIATE AIEE

## Synopsis

A historical review of advances in the design of high-speed cathode-ray oscillographs and in particular a description of the development, performance, and application of a new type oscillograph is presented in this paper. The new instrument embodies a sealed-glass, high-vacuum, hot-cathode, cathode-ray tube for operation at 15,000 volts.

SINCE its birth in 1897[2] the cathode-ray oscillograph has maintained a position of unchallenged and ever-increasing importance in the realm of problems relating to high-speed electrical phenomena. It owes this distinction to its inherent capability of faithfully recording electrical transients of extremely short duration. Among many other accomplishments the cathode-ray oscillograph has contributed enormously to the progress in the perfection of electrical insulation and to a better understanding of insulation problems in general. For example, the knowledge of the characteristics of electrical stresses produced by lightning disturbances on power transmission and distribution systems has been greatly expanded. As a result of these studies, standardized high-voltage impulse tests are now widely made in the industry's laboratories on electrical equipment and apparatus using artificial lightning of prescribed wave shapes. The modern exact impulse-testing technique of today is quite unthinkable without the cathode-ray oscillograph. Likewise the cathode-ray oscillograph has been indispensable in the studies of recovery voltages during circuit interruption and thus in a large measure responsible for the present state of perfection of the modern circuit breaker.

The evolution of the cathode-ray oscillograph, from its early beginning to the various practical forms which are in use today, has occupied a period of 40 years. It would be impossible here to give a full and detailed account of all the valuable developmental work that has been done. However, a brief survey of the principal steps in the development is made below to serve as a background for the new cathode-ray oscillograph which is described in this paper.

## Historical Review

The earliest cathode-ray oscillograph tube which Braun[2] invented in 1897 consisted of a sealed evacuated glass tube, a "cold" cathode, an anode, a diaphragm with a small hole at its center and a fluorescent screen. The electrons, originating at the cathode, traversed the aperture in the diaphragm and impinged on the fluorescent screen to produce there a luminous spot. Shortly after, a magnetic concentration coil[3] was added by means of which the luminous spot could be focused. At first the electrons forming the cathode-ray beams were deflected magnetically; later, electrostatic deflection plates were added. With early tubes of this kind, at excitation voltages of 30 kv, Zenneck photographed fluorescent screen traces of electrical events of one millisecond duration.[7] During the course of the years the original Braun tube was gradually improved[13] by adding a hot cathode, gas, or electrostatic focusing means, and beam intensity grid controls. Today this type of tube is widely available commercially and is commonly used in low-voltage cathode-ray oscillographs of the repeating-time-axis type for the study of recurring phenomena. In slightly modified form it now also is finding an important place in the field of television.

Because of its recording speed limitations the early Braun tube was found inadequate to satisfy a growing demand for higher and higher recording speeds. This led to a radically new avenue of attack and Dufour in 1914 introduced the photographic plate inside the vacuum to let the electrons impinge directly on the photographic emulsion.[8] He used vacuum pumps to obtain and hold the necessary operating vacuum after insertion of the photographic film. At cathode excitation voltages of 50 or 60 kv Dufour obtained a recording speed of 1,000 kilometers per second. The early Braun tube had a recording speed of perhaps one kilometer per second. Based on his earlier experiments Dufour constructed the first practical cathode-ray oscillograph of the so-called internal-photography type, a description of which he published in 1920.[10] For an excellent history of the cathode-ray oscillograph with a complete bibliography up to 1925 reference is made here to a paper by MacGregor-Morris and Mines.[13]

The successful production of a practical high-speed cathode-ray oscillograph by Dufour[10] stimulated many others to follow his lead. Numerous investigators, among them Dufour himself, Rogowski[19] and Flegler, Gabor,[20] Norrinder,[22] Wood,[12] and Knoll,[29] developed new artifices such as improved methods of focusing by the addition of a second concentrating coil, division of the vacuum chamber into 2 sections having different degrees of vacuum, new shapes of cathodes and anodes, beam traps and improvements in the vacuum system. Modified forms of the Dufour-type high-voltage internal recording instruments for practical use in laboratory and field work

A paper recommended for publication by the AIEE committee on instruments and measurements. Manuscript submitted March 26, 1937; released for publication April 24, 1937.

H. P. KUEHNI and SIMON RAMO are employed in the general engineering laboratory of the General Electric Company, Schenectady, N. Y.

2. For all numbered references, see list at end of paper.

**Figure 1. General Electric cathode-ray oscillograph, type HC-15, front view**

were built in this country by the General Electric Company,[26] by Professor R. H. George,[26] and the Westinghouse Electric & Manufacturing Company.[38] Professor George used a hot cathode and electrostatic beam focusing. As a culmination in the quest for high recording speeds, Rogowski[32] in 1930 succeeded in obtaining the enormous speed of about 60,000 kilometers per second, which is $^1/_5$ the speed of light. Because of the finite velocity of the electrons this writing speed is considered to be the practical limit for the cathode-ray oscillograph. The literature from 1930 to date includes descriptions of several practical high-voltage, internal recording type instruments, some equipped with high-speed rotating film drums especially adapted to switchgear testing work (see bibliography). As a result of highly interesting development work Rogowski and his associates recently have obtained surprisingly high writing speeds with a cold-cathode type instrument at voltages as low as a few thousand volts.[64] This result was due to extremely high beam currents made possible by the use of very narrow discharge tubes having relatively high gas pressures.

During the last few years an increasing number of investigators have been studying the possibilities of obtaining high-speed oscillographic records with the film outside of the vacuum. This came about quite naturally with the growth of the commercial impulse-testing practice and the increased applications of the cathode-ray oscillograph to engineering problems. One of the principal difficulties encountered with inside recording results from the necessity for breaking the vacuum to renew a film. Despite great refinements in vacuum technique[59] the time for obtaining the proper operating vacuum after renewal of a film is not always reliably predictable. Numerous factors contribute to this behaviour. Probably the more prominent ones are unavoidable air leaks which are difficult to locate, the removal of moisture and other impurities from the oscillograph vacuum chamber, and the maintenance of the correct vacuum for best oscillograph performance at a given writing speed.

The earliest method used to obtain oscillograph records outside of the vacuum was to photograph with a camera the luminous trace on the oscillograph fluorescent tube screen. However, because of the recording speed limitations existing at that time, this method was abandoned. The solution for high-speed external recording was sought first with the aid of the Lenard[1] window. This is a very thin vacuum-tight membrane supported internally by a reinforcing grid against the external atmospheric air pressure. By using extremely high tube excitation volt-

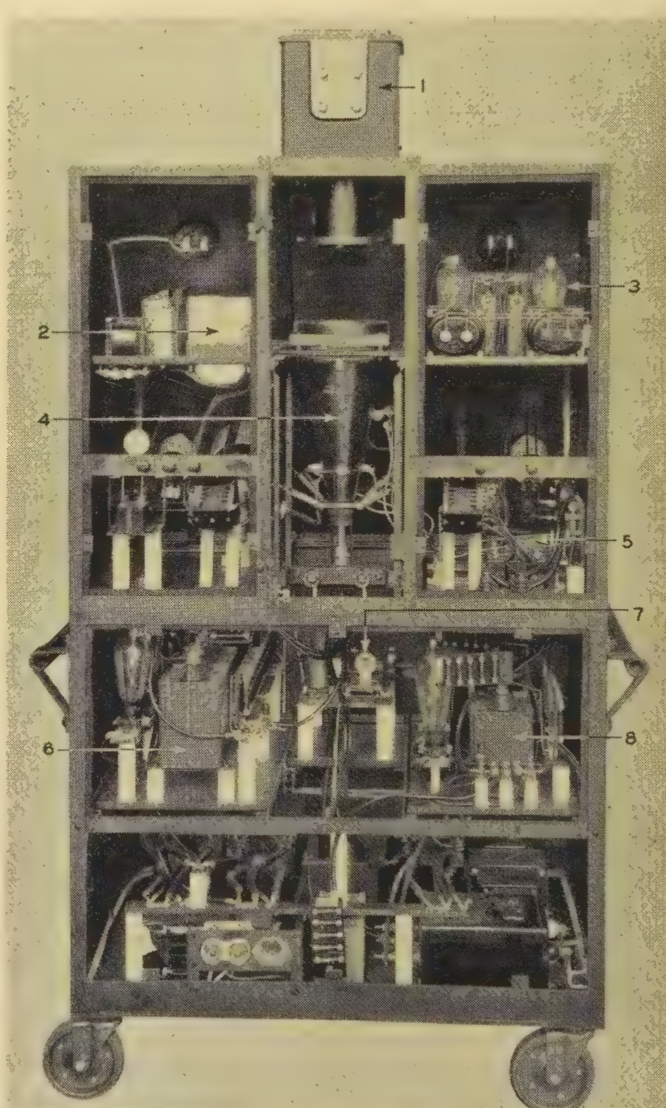



**Figure 2. General Electric cathode-ray oscillograph, type HC-15, rear view**

1. Recording camera
2. Time-axis-calibration oscillator
3. D-c calibration unit
4. Cathode-ray tube
5. Sweep-circuit unit
6. Cathode-excitation-circuit unit
7. Thyratron beam-initiating unit
8. Sweep-initiating unit

ages it was shown by Coolidge[18] that large amounts of electrons can be made to traverse a window of the Lenard type. Knoll[34] first built a practical cathode-ray oscillograph equipped with Lenard windows and obtained recording speeds of 5,000 kilometers per second with a photographic film held against the window (contact exposure) and a cathode excitation voltage of 75 kv. Miller and Robinson[61] have provided a Lenard window attachment for their conventional type of internal photography instrument.

Another line of attack in obtaining oscillographic records by contact exposure has been the use of a glass window coated with fluorescent material on the inside.[14] In this case the light radiation from the fluorescent screen is used to blacken the film. Investigations have been made along this line by a number of workers, Freisewinkel[68] and others, and high recording speeds were obtained in some cases. However, it also was found that unless a very thin glass window is used, the light dispersion will result in a blurred record.[73] Of course, it was known that sharply focused records can be obtained with a camera—which method places no restrictions on the thickness of the glass window—but here only a very much smaller part of the available light is used.

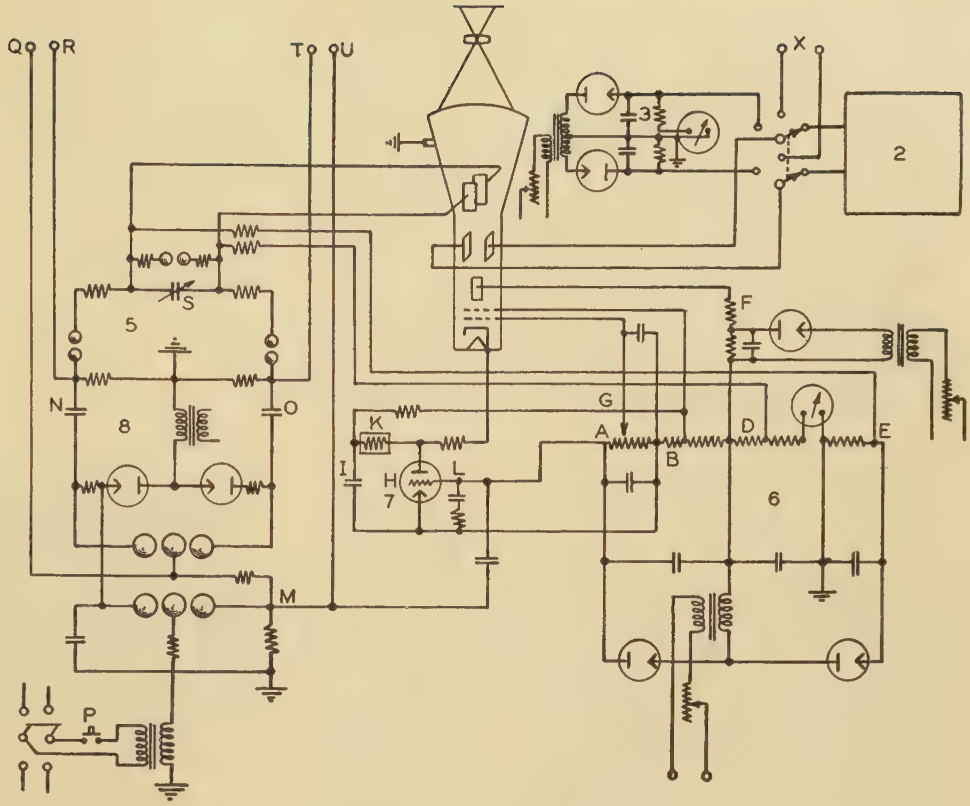



**Figure 3. Simplified schematic oscillograph circuit diagram**

2—Time-axis-calibration oscillator
3—D-c calibration unit
5—Sweep-circuit unit
6—Cathode-excitation-circuit unit
7—Thyratron beam-initiating unit
8—Sweep-initiating unit

With the availability of commercial high-speed photographic lenses and with the attainment of sharply focused beams and exceedingly high fluorescent spot intensities one of the most interesting trends of recent years is the return to the simple external camera method of recording as used in connection with Braun's tubes. Following earlier experiments by Rogowski[41] and his associates, Dodds[56] in 1933 reported the recording by external camera of speeds of 30,000 kilometers per second at 90 kv cathode excitation with a cold-cathode tube. A year later Gondet and Beaudouin[66] described a new Dufour hot-cathode vacuum-pump type oscillograph with external-camera photography.

It having been demonstrated that very high recording speeds can be obtained by photographing the fluorescent screen from the outside, consideration was given again to a complete sealing off of the tube and the resulting elimination of vacuum pumps. Rogowski and Szeghö[52] developed a permanently sealed glass oscillograph tube with cold cathode and zinc sulfide fluorescent tube screen for 40 or 50 kv excitation voltage. The tube was hydrogen filled for protection of the cathode and to obtain a high spot intensity. Provision is made to diffuse hydrogen into the tube to replenish the loss of hydrogen through clean-up action. As cold cathodes are subject to crater formation, a loosely mounted spherical cathode was used which can be turned to expose a fresh surface by lightly tapping the tube. A complete oscillograph embodying a tube of this type was described by Parker-Smith, Szeghö, and Bradshaw[78] in 1935.

In the above brief historical review it was obviously impossible to mention all of the numerous and valuable contributions that were made toward the gradual perfection of the high-speed cathode-ray oscillograph. However, an extensive bibliography covering the cathode-ray oscillograph development, with particular emphasis on the high-speed type for transient recording, is given at the end of this paper.

## The New Cathode-Ray Oscillograph

It has been shown that the cathode-ray oscillograph is capable of enormous recording speeds. However, when we examine the recording-speed requirements from a practical engineering point of view we find that in most of the fields of application of the oscillograph ultrahigh speeds are not required. This applies particularly to impulse-testing work, to the study of lightning and lightning protection, and to investigation of switchgear problems. Because of the large dimensions of the circuits involved

the transients in these circuits inherently can be but moderately fast. Experience has shown that in this important field a recording speed of 10 inches per microsecond (250 kilometers per second) is sufficient for most practical purposes.

Having recognized this fact, the development of a new cathode-ray oscillograph was undertaken with the object of producing an instrument with sufficient recording speed to meet the practical requirements stated above. It was believed that by omitting the ultrahigh-speed feature and by employing a sealed cathode-ray tube requiring no vacuum pumps, and external camera photography, the apparatus would become simpler and less costly.

## The New Cathode-Ray Tube

The development of a cathode-ray tube to meet the above specifications had its origin in the high-vacuum hot-cathode glass type of cathode-ray tubes described by Zworykin[44] and Metcalf.[54] In recording-speed tests made with the General Electric type *FP*-53 cathode-ray tube, single sweep traces of 100,000-cycle oscillator waves were successfully photographed at an anode voltage of 10,000 volts, the maximum tube rating. The more than linear growth of the recording speed, with increasing anode voltage, observed in the tests, suggested further tests at anode voltages higher than 10,000 volts. Therefore, additional tests at higher voltages were made and the voltage was finally boosted to as high as 18,000 volts. The results indicated that beginning at around 15,000 volts standard impulse waves like the 1 x 5- and the $1^1/_2$ x 40-microsecond waves could satisfactorily be recorded. Thus it was quite definitely established that a tube of this type was applicable for the field intended for it.

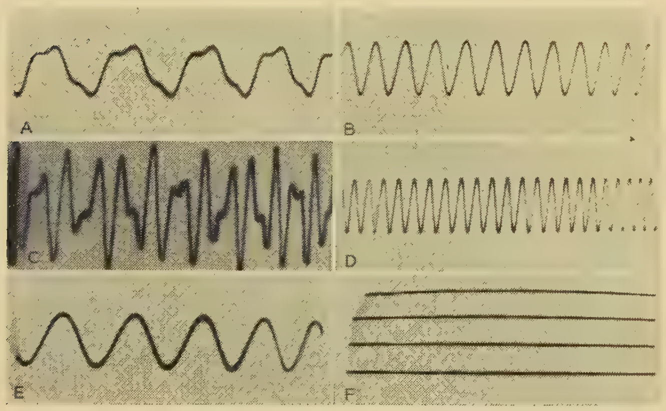



**Figure 4. Oscillator oscillograph records**

*A*—100,000 cycles per second
*B*—500,000 cycles per second
*C*—500,000 cycles per second
*D*—2,000,000 cycles per second
*E*—2,000,000 cycles per second
*F*—D-c calibration record showing 250-volt steps

However, although the cathode-ray tube used stood up quite successfully under the added voltage stresses in these early tests, considerable difficulties were first encountered in attempting to reproduce this tube commercially for continuous operation at 15,000 volts. The most annoying and stubborn obstacles were internal discharges, flashovers, and field currents. These tended to render the tubes sometimes completely inoperative. Most often, however, the local field currents distorted the electrostatic focusing field, so that a sharp focus was not obtainable, and other times they caused a flickering, disturbing screen glow. After many disappointments these difficulties were finally traced to residual gases liberated by the high-speed electrons from the internal tube parts. This discovery led to the adoption of added refinements of the manufacturing processes, mainly during the evacuation stages, and in conjunction with the R. C. A. Manufacturing Company, Radiotron Division, a completely reliable practical 15,000-volt tube known as type RCA-912 was ultimately produced.

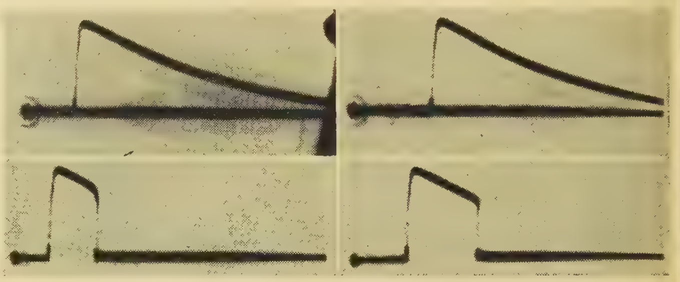


**Figure 5. Impulse oscillograph records**

$1^1/_2$x40-microsecond impulse waves and rod gap flashovers

## Description of the Oscillograph

The new oscillograph, described in the following, was built around the cathode-ray tube, the successful development of which was discussed above. On account of the relatively low cathode-tube operating voltage used, a very compact arrangement of the complete oscillograph equipment was made possible. Thus there were installed in a single cabinet shown in figure 1 the following component parts: the cathode-ray tube and recording camera; auxiliary circuit units for the cathode excitation and focus of the tube, for the automatic initiation of the cathode-ray beam, for producing the sweep and for the proper time co-ordination of the oscillograph with impulse generator or other external circuits; an oscillator for the time axis calibration; and a d-c supply unit for the oscillograph deflection calibration.

The physical arrangement of the various circuits shown in figure 2 presented many interesting problems. Inasmuch as sharp voltage impulses are used in the oscillograph to perform certain precise timing functions with fairly large currents involved the circuits had to be critically arranged for minimum mutual interference. Also undesirable magnetic fields resulting in a disturbed cathode-

ray beam deflection were carefully eliminated by partial field compensation and shielding. A considerable study was also devoted to the proper arrangement of the deflection-plate-circuit leads and all other leads to prevent pickup through magnetically or electrostatically induced voltages from auxiliary timing circuits operating at as high as 7,500 volts. The cathode-ray tube at 15,000 volts tube voltage was measured to have a deflection sensitivity of approximately 500 volts per inch.

In order to obtain a clear understanding of the purpose and function of each oscillograph circuit, these circuits will now briefly be described.

### The Oscillograph Circuits

In figure 3 is shown a simplified schematic diagram of the oscillograph circuits. For the production of the cathode-ray beam, the tube requires proper d-c potentials for the several elements. These voltages are derived from the cathode-excitation circuit shown at the right of figure 3. For this purpose a simple voltage-doubling circuit was used with bleeder resistance *A—E*. The control-grid rheostat was proportioned so that the potential *G* may be varied from complete shut-off of the beam to full intensity. It was also found desirable to provide a separate rectifier circuit for independently adjusting the focusing potential *F*. For the prevention of d-c voltage fluctuations all essential d-c potentials were carefully stabilized with capacitors.

When the oscillograph tube is to be operated at maximum intensity as required for high-speed recording, the time during which the cathode-ray beam is on must be limited. This is necessary because a prolonged high-intensity beam may not only damage the tube screen, but may even soften the glass locally. For the proper time duration of the cathode-ray beam the automatic beam-initiating circuit unit shown in the center of figure 3 was developed. It is seen to consist essentially of a thyratron capacitor resistance discharge circuit *HIK*. For the discharge resistor *K*, thyrite was used which transmits approximately one ampere at 1,000 volts and 0.001 ampere at 100 volts. The circuit operates as follows: By applying a positive voltage impulse to the thyratron grid *L* the capacitor discharge is precipitated. When the discharge current has dropped to a critical value of approximately one milliampere the negative thyratron grid bias shuts off the current and the capacitor charges again slowly through the high charging resistor shown. During the discharge period the voltage drop across the thyratron tube *H* remains approximately constant at around 20 volts. By the use of the thyrite resistor mentioned, instead of an ordinary resistor, it was intended never to let the capacitor voltage drop to less than approximately 100 volts. This special circuit feature was developed to give a sharp cathode-ray beam shut-off as discussed below. After the application of the positive initiating impulse on the thyratron grid *L* the tube voltage quickly drops to a low value and remains essentially at that value until the tube current has reached the critical shut-off point. When the tube shuts off, the voltage instantly rises to about 100 volts and then increases slowly again to the initial value as the capacitor recharges. Referring to the diagram the thyratron anode is connected to the cathode-ray tube cathode through a resistor and the thyratron cathode is connected to *B*. Before the initiation of the thyratron discharge circuit the cathode of the cathode-ray tube is seen to have a positive potential bias with respect to the beam intensity control grid. This is, of course, equivalent to a negative control-grid bias. During the transmission of current through the thyratron, this bias is removed and the cathode-ray beam is on. Owing to the use of the thyrite resistor described above the beam shuts off instantly when the current through the thyratron tube ceases to flow because of the quick rise of the thyratron anode voltage. The resistor shown between the thyratron anode and the oscillograph tube cathode was added to prevent local oscillations. The initiation and timing of the cathode-ray beam could, of course, have been accomplished by swinging the cathode tube control grid rather than the cathode. However, the solution described was found to be more convenient.

The positive initiating impulse for the thyratron grid *L* is obtained from a group of circuits which were designed to provide suitable voltages for the sweep deflection, and the proper time correlation of the oscillograph with the impulse generator or other external circuits. These circuit units are shown schematically in the diagram of figure 3 on the left.

By pressing pushbutton *P* the 3-electrode gap of the primary initiating circuit breaks down near the negative crest of the initiating transformer voltage. The capacitor discharges into the resistor shown and a very steep positive polarity voltage impulse of 7,500 volts appears at *M*. This impulse is transmitted to the thyratron grid *L* through the coupling capacitor shown and the cathode-ray beam comes on and stays on for a predetermined short time. The voltage impulse at *M* is also transmitted through a delay resistance to the midsphere of the 3-electrode gap of the sweep-initiating unit, causing these gaps to break down. The time delay of the gap breakdown was designed to be approximately 20 microseconds. The 2 capacitors of this circuit discharge through the resistors *NO*. A negative polarity voltage of 7,500 volts instantly appears at *N* and a voltage of equal magnitude but of positive polarity appears at *O*. The time constant of this circuit was designed to be 50,000 microseconds so as to give essentially a square voltage wave (d-c voltage) for

Wave-front sphere-gap spark-overs and 2,000,000-cycle oscillator waves with harmonics

**Figure 6. High-speed impulse records**

the excitation of the sweep circuit whose time constant is very much less.

The square voltage wave at $NO$ is applied to the sweep capacitor $S$ through charging resistors by breaking down a pair of small gaps. This causes the sweep voltage on capacitor $S$ gradually to rise, moving the cathode-ray beam sideways along the time axis. When the voltage on $S$ has reached approximately 3,000 volts the small protective gap across $S$ breaks down. The resistors in series with this gap were so designed in proportion to the charging resistors of $S$ that the voltage on $S$ remains essentially constant after the protective gap breakdown. The sweep voltage of 3,000 volts is sufficient to deflect the cathode-ray beam off the tube screen where it will remain until the thyratron tube of the beam initiating unit shuts it off.

As may be recognized in the circuit diagram, the sweep initiating unit and the sweep itself are balanced with respect to ground. A carefully balanced design was developed to eliminate pattern distortions on the oscillograph-tube screen. When an unbalanced sweep was used, the deflection amplitude obtained with a given voltage was found to be larger at one end of the time axis than at the other end.

In order that the cathode-ray spot may start from the edge of the tube screen instead of from the center, the sweep capacitor $S$ and the sweep deflection plates connected to it must have an initial bias voltage of polarity opposite to that of the sweep voltage. This bias voltage was conveniently tapped off at $D$ and $E$ of the cathode excitation circuit as shown. This necessitated the use of the small gaps in the sweep circuit to isolate the sweep deflection plate circuit until the initiation of the sweep.

A selector switch was installed to connect to the vertical oscillograph deflection plates either the oscillograph terminals $X$, the d-c calibrating unit, or the time axis calibrating oscillator. The selector switch, the d-c calibrating unit and the oscillator are shown on the right of the cathode-ray tube in the diagram of figure 3.

### The Recording Camera

Considerable developmental work was done to produce a fast lens system giving a one-to-one magnification ratio. Such a lens was produced by the Bausch and Lomb Optical Company and it is used in the photographic camera shown in figures 1 and 2. It gives a full-size reproduction of the cathode-tube screen image. This feature was obtained by the use of 2 lens systems of equal focal lengths connected in series and mounted in one lens barrel. The cathode tube screen was placed at the focal point of one lens and the image appeared at the focal point of the other. Two separate corrective negative lenses were added to compensate for some field curvature and also to partly compensate for the spherical curvature of the cathode tube screen. The lens assembly was designed to have a nominal lens speed of $f3$.

### Oscillograph Records

In designing the oscillograph, consideration was given to a practical photographic equipment which can be operated by anybody with average experience; thus the handling of the films does not require special refinements inasmuch as commercial films and developers may be used. Supersensitive panchromatic film was found to give the best practical results, but for moderately fast work excellent results were also obtained with Kodak Verichrome film.

In figure 4 are shown reproductions of oscillator oscillograms obtained with the camera described above. Attention is called to the uniform deflection along the entire sweep. This result is due to the use of the balanced sweep circuit described above. Typical records of $1^1/_2$x40 microsecond impulse waves are shown in figure 5.

A set of interesting high-speed records obtained with a sweep of 2 microseconds and a small commercial $f2$ camera are shown in figure 6.

This type of oscillograph may also readily be adapted to rotating film drum recording. In this case only one pair of deflection plates is used and the luminous spot on the tube screen is projected on the moving film by means of a photographic lens. For this application the cathode-ray tube used contains a fluorescent substance having a very short persistence of fluorescence. With film speeds of 500 feet per second oscillatory waves of as high as 100,000 cycles per second were successfully recorded.

By the use of more than one cathode-ray tube multi-

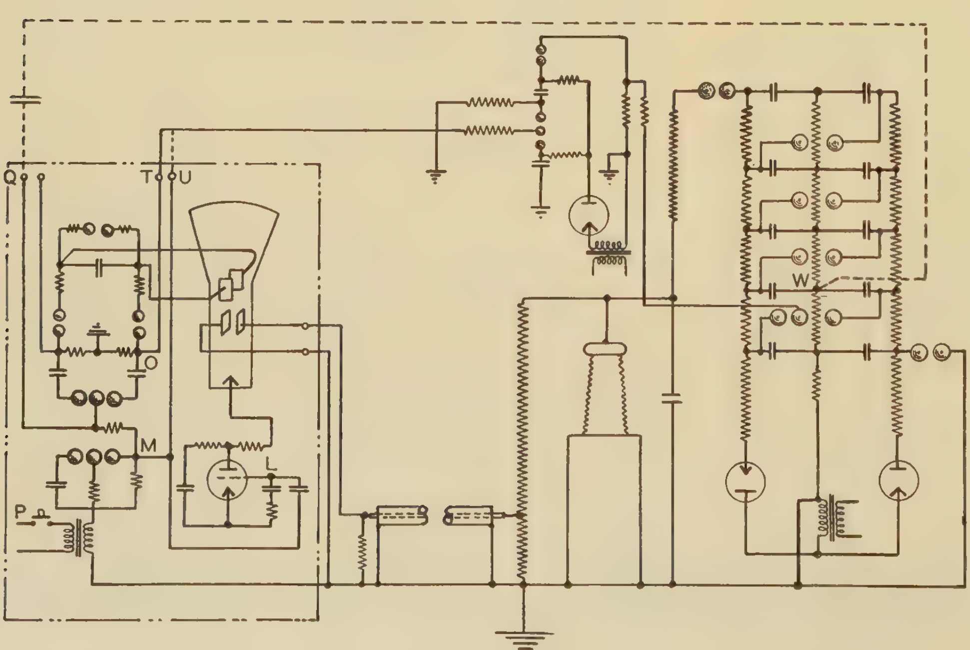



Figure 7. Diagram of oscillograph and impulse-generator co-ordination

circuit recording instruments may be built. Several 3-tube cathode-ray oscillographs are now in use in the General Electric Company.

In one of these instruments the persistence of fluorescence is made use of. The cathode-ray beam is made to sweep across the tube screens recurrently by means of a saw-tooth wave time axis oscillator. Upon occurrence of the fault to be recorded, a relay quickly operates the triggered camera shutter and a snapshot of the tube screens is thus taken. In spite of the time delay introduced by the relay and shutter, the camera successfully photographs the "memory" (persistence of fluorescence) of the fault on the tube screens.

In the development and design of this oscillograph the adoption of 15,000 volts for the cathode tube was quite arbitrary and does, therefore, not represent a final limit for this type of tube. It is believed to be entirely feasible to produce still higher voltage tubes if the range of this type of instrument is to be extended into fields requiring higher recording speeds.

## Application of the Oscillograph to Impulse Testing

There are many ways of co-ordinating a cathode-ray oscillograph with impulse generator equipment and it would be impossible here to describe them all. The engineers concerned with this work have always liked to resort to their own ingenuity for accomplishing desired results and the competition between the various groups has made for remarkable refinements in the art. In order to illustrate the performance of the new oscillograph a method is given of co-ordinating the oscillograph with a Marx-type impulse generator. This method was successfully used in the Schenectady high-voltage laboratory of the General Electric Company.

The simplified circuits are shown schematically in figure 7. As shown, a small 2-stage Marx circuit is used to act as an intermediate initiating circuit between the oscillograph and the impulse generator. The intermediate circuit receives its initiating impulse from the cathode-ray oscillograph and its output in turn is used to trip the impulse generator 3-electrode gap.

In taking an impulse wave record the sequence of events is briefly as follows: With the face held against the viewing window on the front panel of the oscillograph and with the eyes focused on the cathode-tube screen, the camera shutter is first opened. Shortly after pushbutton $P$ is pressed. This causes the 3-electrode gap of the primary oscillograph initiating unit to break down and the impulse from $M$ fires the thyratron tube of the beam-initiating unit. The cathode-ray beam appears on the left edge of the tube screen where it remains stationary. However, within about 20 microseconds the impulse from $M$ also trips the 3-electrode gap of the sweep-initiating circuit and the sweep begins. Simultaneously a voltage impulse of 7,500 volts from $O$ through terminal $T$ travels out through some delay resistance to the trip gap of the intermediate initiating circuit whose output in turn precipitates the impulse generator discharge. The voltage divider leads from the impulse-generator discharge circuit bring the desired voltage impulse to the oscillograph deflection plates. The luminous cathode-ray spot now traces the wave shape which can be seen at the same time the photographic record is taken and the spot finally disappears at the right edge of the cathode tube screen where it is automatically shut off. The camera shutter is now closed and the record is taken.

When very fast sweeps are employed requiring ultra-precision timing, the sequence of the various circuit initiating events is slightly altered. The first impulse from $M$ which establishes the cathode-ray beam is now used to initiate through terminal $U$ the intermediate circuit and impulse generator before the sweep begins. As shown in dotted lines in figure 7 a portion of the impulse generator voltage from $W$ is used to trip the gaps of the sweep-initiating unit through the oscillograph terminal $Q$. This takes place before the arrival of the impulse from $M$ on the same sphere. This modification was found to provide very sharp timing between the start of the sweep and the precipitation of the impulse generator discharge as illustrated by the fast records shown in figure 6.

In conclusion a practical high-speed cathode-ray oscillograph was successfully constructed with external camera photography, incorporating a sealed glass cathode-ray tube, capable of recording transients at a recording speed of 250 kilometers per second (10 inches per microsecond). It was shown that higher recording speeds are not needed in most practical fields of application.

## Bibliography


1. On the Absorption of Cathode Rays, P. Lenard. *Annalen der Physik*, volume 56, 1895, pages 255–75 (in German).

2. A Means for Demonstrating and Studying the Time Variation of Varying Currents, F. Braun. *Annalen der Physik*, volume 60, 1897, pages 552–9 (in German).

3. Investigation of the Velocity and Magnetic Concentration of Cathode Rays, E. Wiechert. *Annalen der Physik*, volume 69, 1899, pages 739–66 (in German).

4. Photographic Current Curves, J. Zenneck. *Annalen der Physik*, volume 69, 1899, pages 838–53 (in German).

5. Cathode-Ray Wave Tracer, H. J. Ryan. AIEE Transactions, volume 20, 1903, pages 1117–26.

6. The Cathode-Ray Oscillograph, R. Rankin. *Electric Journal*, volume 2, 1905, pages 620–31.

7. Instantaneous Braun Tube Photographs, J. Zenneck. *Physikalische Zeit.*, volume 14, 1913, pages 226–99 (in German).

8. Cathode-Ray Oscillograph, A. Dufour. *Comptes Rendus*, volume 158, 1914, pages 1139–41 (in French).

9. Piezo-Electricity and Its Applications, Sir J. J. Thompson. *Engineering*, volume 107, 1919, pages 543–44.

10. Cathode-Ray Oscillograph, A. Dufour. *Journal de Physique et le Radium*, volume 1, 1920, pages 147–60 (in French).

11. A Low Voltage Cathode-Ray Oscillograph, J. B. Johnson. *Physical Review*, volume 17, 1921, pages 420–21.

12. The Cathode-Ray Oscillograph, A. B. Wood. *Journal* of the Institution of Electrical Engineers, volume 63, 1925, pages 1046–55.

13. Measurements in Electrical Engineering by Means of Cathode-Rays, J. T. MacGregor-Morris and R. Mines. *Journal* of the Institution of Electrical Engineers, volume 63, 1925, pages 1056–1107.

14. A Note on the Cathode-Ray Oscillograph, F. R. Terroux. *Journal* of Franklin Institute, volume 200, 1925, pages 771–4.

15. Application of the Braun Tube as a High Frequency Oscillograph, H. Norinder. *Teknisk Tidskrift, Elektroteknik*, volume 55, II, 1925, pages 152–57 (in Swedish).

16. Cathode-Ray Oscillograph, W. Rogowski and E. Flegler. *Archiv für Elektrotechnik*, volume 15, 1925, pages 297–303 (in German).

17. Cathode-Ray Oscillograph, W. Rogowski and W. Grösser. *Archiv für Elektrotechnik*, volume 15, 1925, pages 377–84 (in German).

18. The Production of High-Voltage Cathode-Rays Outside of the Generating Tube, W. D. Coolidge. *Journal* of the Franklin Institute, volume 202, 1926, pages 693–727.

19. New Type of Construction for the Cathode-Ray Oscillograph, W. Rogowski, E. Flegler, R. Tamm. *Archiv für Elektrotechnik*, volume 18, 1927, pages 513–24 (in German).

20. Improvements in Oscillographic Recording of Surges, D. Gabor. *Archiv für Elektrotechnik*, volume 18, 1927, pages 48–55 (in German).

21. Cathode-Ray Oscillographs and Their Uses, E. S. Lee. *General Electric Review*, volume 31, 1928, pages 404–12.

22. The Cathode-Ray Oscillograph, H. Norinder. AIEE Transactions, volume 47, 1928, pages 446–55.

23. Electric Surges, W. Rogowski, E. Flegler. *Archiv für Elektrotechnik*, volume 20, 1928, pages 635–6 (in German).

24. Cathode-Ray Oscillograph of High Voltage Sensitivity, E. Sommerfield. *Archiv für Elektrotechnik*, volume 20, 1928, pages 607–18 (in German).

25. Further Development of the Dufour Cathode-Ray Oscillograph for Recording Lightning Phenomena, K. Berger. Schweiz-Electrotechnischer Verein *Bulletin*, volume 19, 1928, pages 292–301 (in German).

26. A New Type of Hot Cathode Oscillograph and Its Application to the Automatic Recording of Lightning and Switching Surges, R. H. George. AIEE Transactions, volume 48, 1929, pages 884–90.

27. New Design of Cathode-Ray Oscillograph and Its Application to Piezoelectric Measurements, S. Watanabe. Inst. Phys. and Chem. Research Tokyo, Scientific Papers, Nos. 212 and 213, pages 82–98 and 99–112, October 20, 1929 (in English).

28. Special Type of Cathode-Ray Oscillograph, H. Norinder. *Zeits. für Physik*, volume 63, 1930, pages 672–84 (in German).

29. Cathode-Ray Oscillograph of the Horizontal Type, A. Matthias, M. Knoll, and H. Knoblauch. *Zeits. für Physik*, volume 11, 1930, pages 276–82 (in German).

30. A Braun Tube for Direct Photographic Recording, M. von Ardenne. *Experimental Wireless*, London, volume 7, 1930, page 66.

31. Sealed Braun Tube of High Output, W. Rogowski and S. Szeghö, *Archiv für Elektrotechnik*, volume 24, 1930, pages 899–900 (in German).

32. Recording Limit of the Cathode-Ray Oscillograph, W. Rogowski, Flegler, K. Buss. *Archiv für Elektrotechnik*, volume 24, 1930, pages 563–6 (in German).

33. Photographic Recording With the Cathode-Ray Oscillograph, M. Knoll. *Elektrotechnische Zeit.*, volume 52, 1930, page 1749 (in German).

34. Recording Fast Transient Phenomena With Cathode-Ray Oscillograph in Free Air as Well as in High Vacuum, M. Knoll. AIEE Journal, volume 49, 1930, pages 463–5.

35. Cathode-Ray Oscillograph With Lenard Window, M. Knoll. *Rev. Scientific Inst.*, volume 1, 1930, pages 507–11.

36. Contact Photography in Cathode-Ray Oscillographs, M. Knoll. *Zeit. für Tech. Physik*, volume 11, 1930, pages 491–3 (in German).

37. External Photography With a Cathode-Ray Oscillograph With Large Window, M. Knoll and B. V. Borries. *Zeit. für Tech. Physik*, volume 11, 1930, pages 493–5 (in German).

38. A Cathode-Ray Oscillograph With Norinder Relay, O. Ackermann. AIEE Journal, volume 49, 1930, pages 285–9.

39. Contribution to the Development of the Cathode-Ray Oscillograph With Cold Cathode, K. Beyerle. *Archiv für Elektrotechnik*, volume 25, 1931, pages 267–76 (in German).

40. High Capacity Cathode-Ray Oscillograph for a 200 KV Deflection Voltage, L. Binder. *Elektrotechnische Zeit.*, volume 52, 1931, pages 735–6, (in German).

41. External Recording of Cathode-Ray Oscillograms With Lens and Camera in the Case of Extremely High-Speed Phenomena, K. Buss and A. Pernick. *Archiv für Elektrotechnik*, volume 25, 1931, pages 545–50 (in German).

42. New Cathode-Ray Oscillograph With Cold Cathode and Preconcentration, H. Boekels. *Archiv für Elektrotechnik*, volume 25, 1931, pages 151–2 (in German).

43. Investigation of Electron Current in the Cold-Cathode Cathode-Ray Oscillograph, E. Rühlemann. *Archiv für Elektrotechnik*, volume 25, 1931, pages 505–20 (in German).

44. Improvements in Cathode-Ray Tube Design, V. K. Zworykin. *Electronics*, November 1931, pages 188–90.

45. Cathode-Ray Oscillograph for Registration in High Vacuum, W. Holzer and M. Knoll. *Zeit. für Instrumentenkunde*, volume 52, 1932, pages 274–81 (in German).

46. Comparison of Electron and Light Blackening of Photographic Plates in Cathode-Ray Oscillographs, K. Buss and A. Pernick. *Archiv für Elektrotechnik*, volume 26, 1932, pages 723–4 (in German).

47. P. Rijlant. *Arch. Int. de Physiol.*, volume 35, 1932, page 326.

48. Blackening of Photographic Emulsions With Low Exciting Potentials in the Cathode-Ray Oscillograph, H. Schäffer. *Archiv für Elektrotechnik*, volume 26, 1932, pages 313–14 (in German).

49. Polyphase Cathode-Ray Oscillograph, M. Knoll. *Elektrotechnische Zeit.*, volume 53, 1932, pages 1101–03 (in German).

50. Technique of the High-Speed Cathode-Ray Oscillograph, F. P. Burch and R. V. Whelpton. *Journal* of the Institute of Electrical Engineers, volume 71, 1932, pages 380–8.

51. Recent Developments in Cathode-Ray Oscillographs, A. B. Wood. *Journal* of the Institute of Electrical Engineers, volume 71, 1932, pages 41–56.

52. Cathode-Ray Oscillograph of the Sealed-off Type and High Power, K. Szeghö. *Archiv für Elektrotechnik*, volume 26, 1932, pages 291–300 (in German).

53. A New Type of Cathode-Ray Oscillograph With Cold Cathode and Pre-Concentration, H. Boekels. *Archiv für Elektrotechnik*, volume 26, 1932, pages 453–6 (in German).

54. A New Cathode-Ray Oscillograph Tube, G. F. Metcalf. *Electronics*, volume 4, 1932, pages 158–9.

55. New Polyphase Cathode-Ray Oscillograph, H. Boekels and H. Dicks. *Archiv für Elektrotechnik*, volume 27, 1933, pages 134–6.

56. External Camera Recording Speed Limits of Cathode-Ray Oscillographs, J. M. Dodds. *Archiv für Elektrotechnik*, volume 27, 1933, pages 531–8 (in German).

57. Arc Extinction Phenomena in High Voltage Circuit Breakers, R. C. Van Sickle and W. E. Berkey. AIEE Transactions, volume 52, 1933, pages 850–7.

58. Cathode-Ray Oscillograph With Low Exciting Potential, W. Rogowski and F. Malsch. *Archiv für Elektrotechnik*, volume 27, 1933, pages 131–3 (in German).

59. Production and Maintenance of Vacuum in the Cathode-Ray Oscillograph and Similar Apparatus, F. R. Benedict. *Instruments*, volume 7, 1934, pages 247–50.

60. Double Cathode-Ray Oscillograph, V. I. Feoktistov. *Russian J. Tech. Phys.*, volume 4, 1934, page 332 (in Russian).

61. Design and Operation of a High-Speed Cathode-Ray Oscillograph, J. L. Miller and J. E. L. Robinson. *Journal* of the Institution of Electrical Engineers, volume 74, 1934, pages 511–19.

62. A Cathode-Ray Oscillograph With Metal Chamber for External Recording of High Speed Phenomena, M. Knoll, H. Knoblauch, B. V. Borries. *Electrotechnische Zeit.*, volume 51, 1934, pages 966–70 (in German).

63. External Recording With the Cathode-Ray Oscillograph, E. W. Freisewinkel. *Archiv für Elektrotechnik*, volume 28, 1934, pages 602–11 (in German).

64. Cold-Cathode Cathode-Ray Oscillograph for Low Exciting Potentials, F. Malsch and E. Westerman. *Archiv für Elektrotechnik*, volume 28, 1934, pages 517–19 (in German).

65. Contribution to the Development of the High Deflection Sensitivity High-Vacuum Glow-Cathode Oscillograph, H. Graupner. *Archiv für Elektrotechnik*, volume 28, 1934, pages 477–85 (in German).

66. New Dufour Cathode-Ray Oscillograph, H. Gondet and Ch. Beaudouin. *Revue Generale de L'Electricite*, volume 36, 1934, pages 291–301 (in French).

67. Fluorescent Materials for Television and Cathode-Ray Oscillograph Purposes, W. Schrobel. *Archiv für Elektrotechnik*, volume 28, 1934, pages 789–97 (in German).

68. Comparative Film Blackening With Internal and External Recording Cathode-Ray Oscillographs, E. W. Freisewinkel. *Archiv für Elektrotechnik*, volume 28, 1934, pages 826–32 (in German).

69. Efficiency and Sensitivity of Braun Tube With Double Concentration, F. Malsch. *Archiv für Elektrotechnik*, volume 28, 1934, pages 349–55 (in German).

70. Investigation of Metal Discharge Tubes for Cathode-Ray Oscillographs With Cold Cathodes, H. Dicks. *Archiv für Elektrotechnik*, volume 28, 1934, pages 50–55 (in German).

71. Dual Vacuum in a Sealed-off Cathode-Ray Oscillograph, K. Szeghö. *Archiv für Elektrotechnik*, volume 28, 1934, pages 445–7 (in German).

72. Electric Lenses for Cold-Cathode Cathode-Ray Oscillograph, F. Malsch and F. A. Becker. *Archiv für Elektrotechnik*, volume 28, 1934, pages 580–6 (in German).

73. Line Sharpness in Cathode-Ray Oscillograph Contact Photography, H. Graupner. *Archiv für Elektrotechnik*, volume 28, 1934, pages 323–5 (in German).

74. Electric Electron Lens for Cathode-Ray Tubes, M. Knoll. *Archiv für Elektrotechnik*, volume 28, 1934, pages 1–8.

75. Sensitive Cold-Cathode Oscillograph of High Power for Low Exciting Potential, E. Westermann. *Zeit. für Tech. Physik*, volume 16, 1935, pages 262–4 (in German).

76. Metal Discharge Tubes, J. M. Dodds. *Archiv für Elektrotechnik*, volume 29, 1935, pages 69–78 (in German).

77. Recording of Transients on Overhead Lines, R. V. Whelpton and F. S. Edwards. *Metropolitan-Vickers Gazette*, volume 15, 1935, pages 371–6.

78. A Cathode-Ray Oscillograph Equipment Embodying a High Voltage Gas-Filled, Sealed-Glass, Oscillograph Tube, S. Parker-Smith, C. Szeghö, and E. Bradshaw. *Journal* of the Institution of Electrical Engineers, volume 76, 1935, pages 656–65.

79. The Oscillographic Equipment of the Switchgear Testing Company. *Engineering*, volume 140, 1935, pages 385–8.

80. A Cathode-Ray Oscillograph With High-Speed Drum Camera Rotating in Vacuo, G. A. Whipple. *Journal* of the Institution of Electrical Engineers, volume 78, 1936, pages 497–515.

81. The Cathode-Ray Oscillograph of the Ampere Laboratory, P. Schirep and M. Sollima. *Revue Generale de L'Electricite*, volume 38, 1936, pages 241–6 (in French).

# Dynamic Balancing of Small Gyroscope Rotors

By O. E. ESVAL
ASSOCIATE AIEE

C. A. FRISCHE
Member Amer. Phys. Soc.

A DIRECT METHOD[1] of balancing is generally possible for any type of rotor provided it can be run in a special fixture for the measurements. However, some rotors due to large size or other restrictions can be run only on their permanent mountings and balancing usually requires more or less "trial and error" testing. On the other hand, certain rotors of the first group that are small in size and may be run in special fixtures, impose unusual obstacles which make it difficult to apply the well-known principles to produce a rational method of dynamic balancing. This paper is devoted to a description of the solution of such a balancing problem.

The present method was originally developed to balance a wheel capable of spinning 30,000 to 40,000 rpm. At that time the production method of balancing small gyro rotors in the Sperry Company consisted of placing small amounts of putty or Vulcatex on the rotor periphery and shifting the position and amount until the rotor felt smooth. The rotor was then drilled in accordance with the position and the amount of putty present. This required skilled operators but at the time seemed to be the only method which produced a satisfactory balance. However, this method broke down when applied to very high-speed rotors, since the operators no longer have a proper sense of "feel" at high frequencies. After the application had been made to the high-speed wheel, it was decided that the method would be very useful for production balancing of air-driven gyroscope rotors such as are shown in figure 4. These rotors are used in the standard airplane flight instruments shown in figure 5. Several factors in this balancing problem are unique. The most important of these is the unusually high degree of balance required. This requirement is peculiar to gyroscopic instruments since very sensitive antifriction bearings must be used for rotor and gimbal bearings. Also it is frequently found that dynamic unbalance, even in small amounts, will excite destructive gyroscopic nutations. This is particularly true of gyros with very free gimbal bearings. Quantitatively, the maximum allowable vibration is of the order of $10^{-5}$ inch at the bearing housing. This is not remote from the threshold of "feeling" on these instruments at 200 revolutions per second. It is understood, of course, that very high-grade, smooth running bearings must be used, otherwise one may mistake the "feel" of bearing "noise" for rotor unbalance. This requires an excellence of running balance that is far beyond the range tolerated in any other type of rotating apparatus.

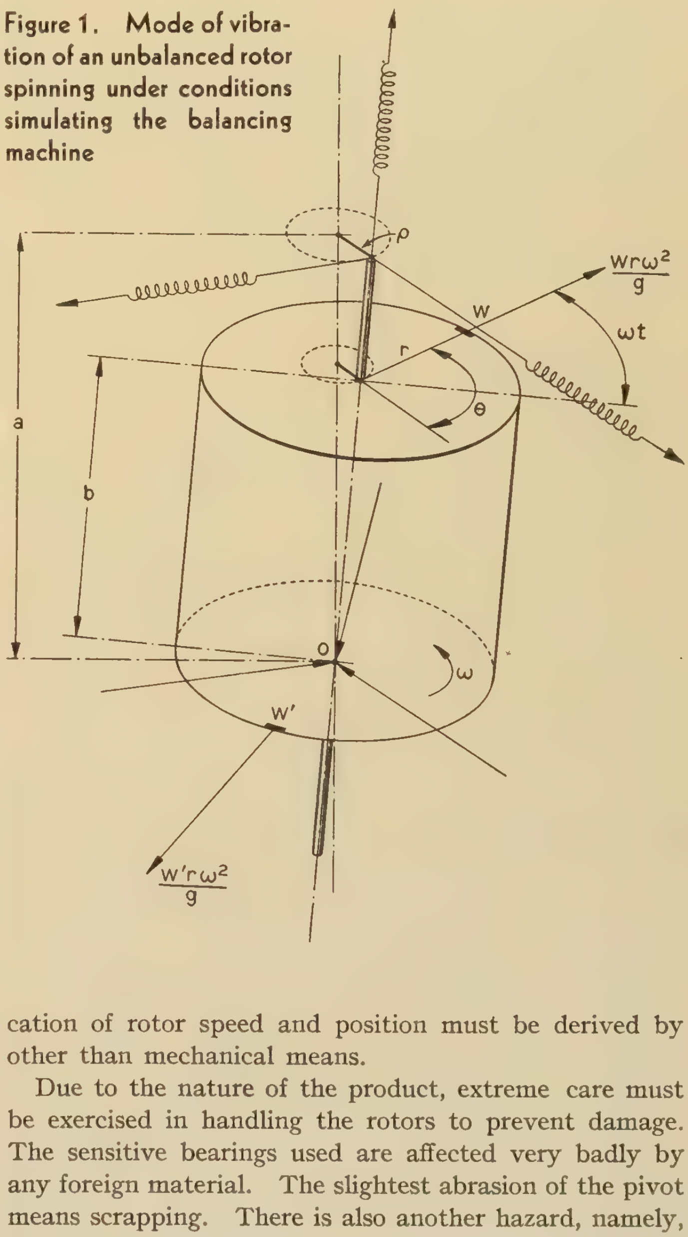
A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted March 13, 1937; released for publication April 21, 1937.

O. E. Esval and C. A. Frische are employed in the research laboratory of the Sperry Gyroscope Company, Inc., Brooklyn, N. Y.

1. A list of references relating to many of the most important rotor balancing methods is given at the end of this paper.

Pivot-type cone bearings are used on these rotors. These are shown on the central shafts in figure 4. The pivots run on ball bearings in the case of the instrument. Due to this type of construction, it is impracticable to connect mechanically to any type of speed indicator, voltage generator, commutator, or interruptor. Furthermore, any mechanical connections would, when removed after balancing, in all probability cause an unbalance. Therefore, any signal which is to be generated for indication of rotor speed and position must be derived by other than mechanical means.

Figure 1. Mode of vibration of an unbalanced rotor spinning under conditions simulating the balancing machine




Due to the nature of the product, extreme care must be exercised in handling the rotors to prevent damage. The sensitive bearings used are affected very badly by any foreign material. The slightest abrasion of the pivot means scrapping. There is also another hazard, namely, the danger of striking the unprotected rotor pivot against some object while it is being removed or assembled in the balancing fixture. Therefore, the machine must be constructed in such a manner that unskilled operators

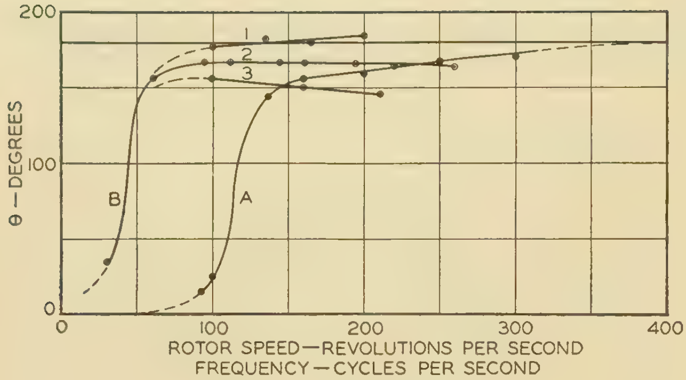



**Figure 2. Phase shift curves**

*A*—Phonograph pickup *B*—Ring pickup

can manipulate it rapidly with the minimum hazard to the finished rotor.

Another condition to contend with is high speed. It must be possible to measure rotor unbalance at a comparatively high speed. This speed may be anywhere from 5,000 to 40,000 rpm. Thus, to obtain high sensitivity, the rotor casing and vibration pickup must be as light as possible and the critical frequency of the mount should be very low with respect to the lowest speed at which we wish to balance.

## Choice of Method

In choosing a method of balancing these gyroscope rotors, we were forewarned that our problem was so different that an unusual machine was necessary. Attempts by various companies interested in up-to-date balancing methods to balance these rotors failed to produce results. The reason, obviously, was that their standard apparatus while excellent for their own product, was not adapted to the small gyro rotors.

## Rotor Mounting

The first attempt at a balancing machine is shown in figure 6. The rotor is mounted in a rigid 3-legged frame. At each end of the frame, in the correction planes, (planes normal to the spin axis which include the balancing weights) are mountings for flat leaf springs 120 degrees apart as shown at the bottom of the frame. The springs can be attached at either end of the frame and their outside ends are secured to a heavy base. The frame is then virtually pivoted at the rotor axis in the plane of the springs. The springs maintain equal rigidity in all planes which include the axis. Therefore, the rotor axis will oscillate in a conical path (this will be found demonstrated in figure 1), the apex of which lies in the plane of the springs. For small vibrations, the damping of such a spring mount is exceedingly low. It is easy to adjust the resonant speed by varying length and thickness of springs and maintain at the same time sufficient rigidity in the plane of the springs to substantially block out the vibration of the end not being measured.

## Reference Signal

Since it is impossible to attach any kind of a signal generator mechanically to the rotor, the obvious way of of obtaining a signal which depends for its phase on a reference mark on the rotor, is the application of the photoelectric cell. A beam of light is reflected from the surface of the rotor to a photocell. A certain part of the rotor surface is highly polished, the rest is not. The rotation, therefore, varies the reflected light and pulsates the photocell current at rotor frequency. This means of voltage generation obviously does not impede motion of the rotor or the frame.

## Vibration Instruments

The first requirement of the vibration instrument is that it must permit adjustment of the phase of the output

**Figure 3. Resonance curves**

*A*—Phonograph pickup

*B*—Ring pickup

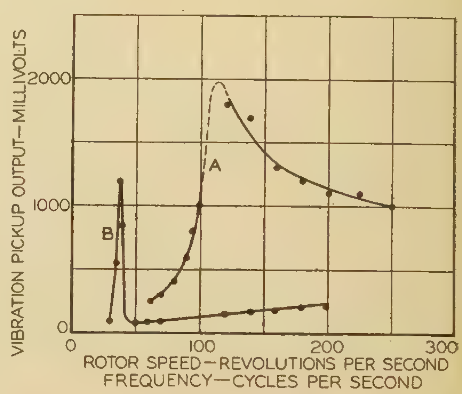
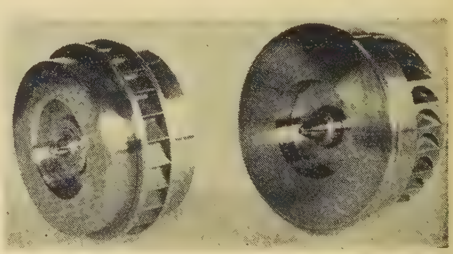



**Figure 4. Gyroscope rotors**



voltage. In practically all other balancing methods, the phase of the reference voltage is adjusted to be in or out of phase with the vibration voltage. But it is inconvenient to adjust the phase of the reference voltage in this device because in moving the optical system around the axis of rotation, the light beam would be intercepted by the frame work. The vibration instrument shown in figure 6 is an ordinary electromagnetic phonograph pickup. It is mounted to rotate on the axis of the needle which rests on the top of the rotor frame. Vibration of the frame is transmitted to the pickup through the needle, thus generating a voltage. The frame vibration is circular around the spin axis but the pickup generates a voltage by only that component of the vibration that lies in one axial plane. Now, to advance or retard the phase of the voltage, it is necessary only to advance or retard the axial plane in which the pickup is sensitive.

This means that rotation of the pickup about the needle axis, adjusts the phase of the output. The dial indicates pickup position. It is apparent that the voltage magnitude is not affected by angular position of the pickup as long as the rotor axis describes a circular path under the influence of an unbalanced rotor.

The voltage output of the pickup is proportional to frequency ($\omega$) and amplitude of the vibration ($\rho$) and is, therefore, a measure of unbalance ($Wr/g$) at any given speed, where $W$ is the unbalanced weight, $r$ is its radial distance from the spin axis, and $g$ is acceleration of gravity. The position of the unbalance is determined by adding to the vibration voltage the reference voltage. The magnitudes are first made equal by attenuation. The pickup is then rotated to the point where the sum of the 2 voltages is zero. The dial reading indicates the position of the unbalance as measured in degrees from some arbitrary reference mark on the rotor. The phonograph pickup was tried first because of its availability and simplicity but it was not entirely satisfactory, as will be discussed later. First, another necessary feature of the system will be discussed.

## Filtering

Figure 7 is what might be called a vibration spectrum of a rotor with bearings and frame. It indicates the relative magnitude (not taking into account the fact that the voltage induced in the pickup is proportional to frequency), of all the harmonics that are present in the vibrations of a fairly well-balanced rotor. The rotor speed is 200 revolutions per second and the amplitude at that frequency is considerably less than some near-by frequencies. Naturally, these other frequencies tend to give an erroneous voltage reading in measuring magnitude and make it impossible to phase against the reference voltage for position. Obviously, filtering is necessary. If the precision of balance required were not so high, the vibration component at rotor speed would still be large and filtering would not be necessary. Under existing conditions, it is, however, a prime requisite. The reference signal also has a high harmonic content so it must be filtered too. The combined output is filtered after the 2 voltages are added together. This precludes the possibility of uncompensated phase shifts in filtering. The schematic wiring diagram, figure 8, shows the method of adding voltages, filtering, and amplifying. A very sharp band-pass filter is used.

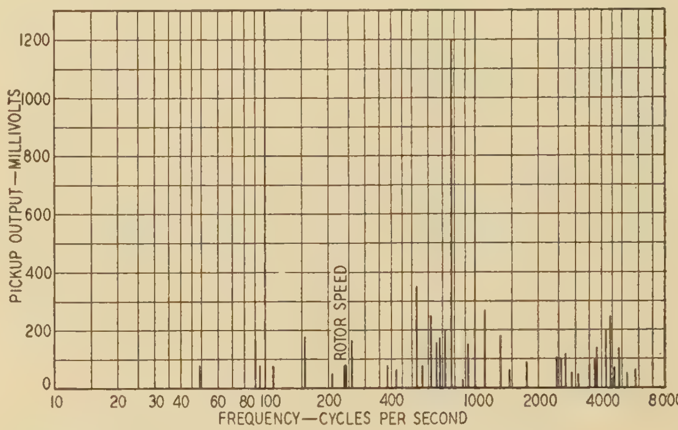



**Figure 7. Gyroscope vibration spectrum**

Vibration frequencies present in a balanced directional gyro rotor case; bearings not perfect

Pickup response is not a measure of amplitude of vibration at various frequencies because output is proportional to frequency

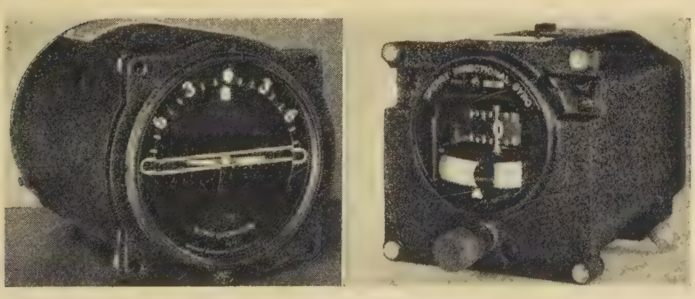


**Figure 5. Flight instruments**

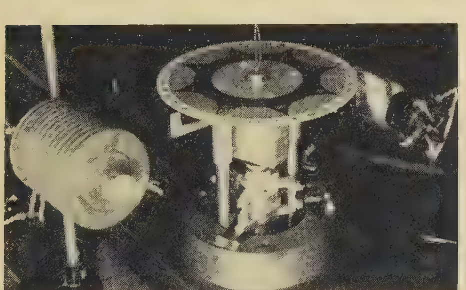


**Figure 6. Experimental machine with phonograph pickup**

## Voltage Balance

In practice, it is found that in order to obtain an accurate indication of unbalance position, the 2 voltages must be very nearly equal. At least one of them must therefore be adjustable. The reference signal is the one adjusted. The effect of imperfectly balanced voltages is shown in figure 9. The slope of the curves is a measure of sensitivity in locating the correct position. The abscissas of this family of curves is the angle ($\alpha$) between minus $e_v$ and plus $e_r$, and the ordinates are their sum ($e$) in per cent of the vibration voltage ($e_v$). Plots at several ratios ($P$) between $e_v$ and $e_r$ are given to show the effect of inequality of the signal voltages. It should be noted that $\alpha$ is the angular error in locating the unbalanced weight.

Let

$$e_v = E_v \cos(\omega t + \alpha - 180°)$$
$$e_r = E_r \cos \omega t$$

When $E_v = E_r$ by adjustment and $\alpha = 0$. Then

$$e_v + e_r = E_v \cos(\omega t - 180°) + E_v \cos \omega t = 0$$

It can then be shown that

$$e/e_v = \sqrt{1 - 2P\cos\alpha + P^2}$$

For small angles this relation can be simplified to

$$e/e_v = \sqrt{(P-1)^2 + P\alpha^2}$$

The curves of figure 9 are a plot of this equation.

Since the slope of the curves is proportional to sensitivity in setting $\alpha$ equal to zero, it is apparent that the voltages must not be unequal by more than approximately one per cent to measure position with an accuracy of one-half a degree. Furthermore, to obtain the same sensitivity of position for small magnitudes, as for large magnitudes, a tapered attenuator on the reference voltage must be used.

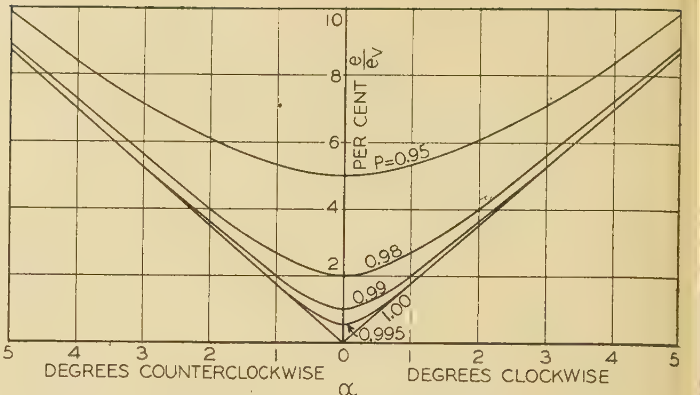



**Figure 9. Positioning error curves**

In order to determine accurately the position of unbalance $\alpha$ must be made zero. To obtain high accuracy in setting $\alpha$ to zero, $P$ must be close to unity

## Phonograph-Type Pickup

The resonance curves of figure 2, curve $A$, and figure 3, curve $A$, indicate that damping is considerable because the angular position is never independent of speed in the operation range. In fact, at 200 revolutions per second a change of 20 revolutions per second results in position change of $2^1/_2$ degrees. Of course, the band-pass filter limits the possible variation in speed, but with air driven rotors, speed changes of less than 10 revolutions per second are difficult to control. Such changes in frequency will not appreciably change the attenuation of the desired signal. A more serious difficulty was the unsuitable critical speed. The curves, figure 2, curve $A$, and figure 3, curve $A$, show resonance at about 115 cycles. Experience indicated that 150 revolutions per second (9,000 rpm) is a good compromise speed at which to balance the rotor. It is undesirable to balance at full speed, 12,000 rpm, because initial unbalance forces are a hazard to rotor pivots. Balancing at 2 speeds was found unnecessary, hence the compromise. Since 150 revolutions per second was found to be the best balancing speed, resonance at 115 revolutions per second put the knee of the curve right at running speed. Such a condition would produce bad errors in position with imperceptible changes in speed. In attempting to lower the resonance speed, several modifications of the mounting and vibration pickup were tried. The pivoting springs were made longer to lower the free resonance of the frame. But, in doing so, the loading effect of the pickup on the system was accentuated to such an extent that all gain in reduced frame resonance speed was lost. This was caused partly by the phenomenon of 2 resonances in series, one of which is the spring mounted frame and the other the natural frequency of the magnetic pickup. They are mechanically connected together by the needle. Various attempts to reduce damping and lower the resonance of the pickup were made but decrease of one effect tended to increase the other. This was an indication that the pickup was the wrong type of instrument. It became necessary to investigate the use of other types of vibration measuring devices. A piezoelectric microphone was given a trial but with little success.

In the course of experiments, it became apparent that the important requirement of the system is a very loose coupling between the oscillating frame and the pickup. The next section describes such a vibration instrument.

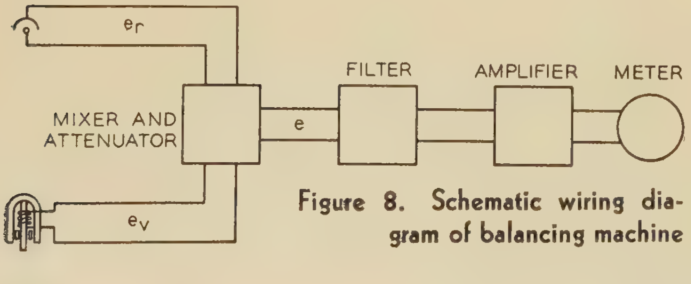



**Figure 8. Schematic wiring diagram of balancing machine**

## Ring-Type Pickup

Figures 10 and 11 illustrate the type of instrument that was finally evolved. This pickup has the desirable feature of having a very loose coupling with the rotor frame. It is noted that there is no mechanical coupling between these parts.

The instrument comprises a permanent horseshoe magnet with a center pole of soft iron on which is wound a coil and a soft iron ring attached to the moving element (rotor frame). The iron ring oscillates with the rotor axis under influence of rotor unbalance. This oscillation is such that the ring moves in an eccentric path around the central pole of the pickup. This motion varies the flux through the center pole periodically and generates a voltage in the coil the frequency of which is rotor frequency. Examination will show that the phase of the voltage can be changed by turning the permanent magnet on the axis of the center pole. The voltage ($e_v$) is proportional to the amplitude ($\rho$) of the circular oscillation and, therefore, is also proportional to unbalance ($Wr/g$) at fixed speed.

With this device, it was possible to obtain the resonance curves as shown on figure 2, curve $B$, and figure 3, curve $B$. The resonance, it is noted, occurs at 40 revolutions per second as compared to 115 revolutions per second with the phonograph type of pickup. This critical speed is sufficiently low to allow very satisfactory operation at 150 revolutions per second. It will be noted that there are several slopes to the $\theta$ curves. $\theta$ is the angle between the displacement vector ($\rho$) and disturbing force ($Wr\omega^2/g$). Number 1 is the first result. It has a

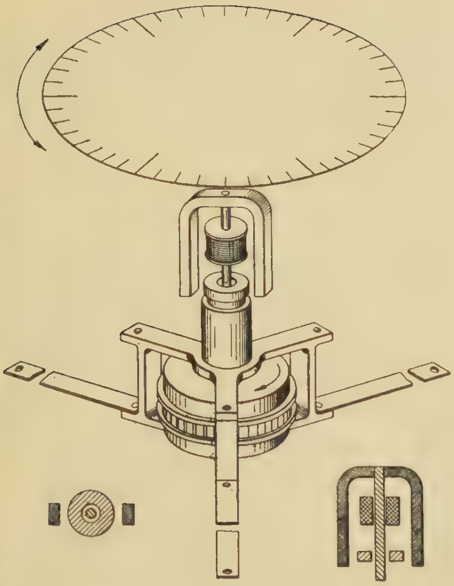


Figure 10. Ring-type pickup

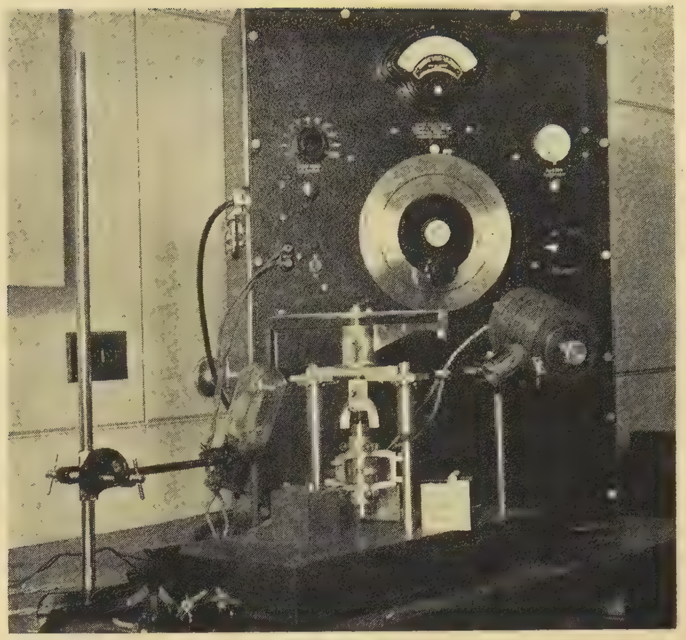


Figure 11. Experimental machine with ring-type pickup

slight change of $\theta$ with speed. This condition is not entirely satisfactory and experiments were made to remedy it. This condition, it was possible to correct in the circuit. Capacity across the photoelectric cell coupling transformer was found to provide means of compensating this relative phase shift. Several values of capacity were inserted across the transformer and the results are shown. One value of capacity, it will be noted, produced practically constant $\theta$ with speed variation in the 150-revolution-per-second region. This is the final arrangement.

The critical speed of the system and phase shifts were now reduced to a very satisfactory value. The basic features of the system were now developed. However, some doubt was raised concerning the practicability, owing to the difficulty in mechanically keeping the axis of the ring concentric with the pole of the pickup. Since the frame on which the ring is mounted is supported on 3 springs, it is apparent that close mechanical alignment is not easy to maintain. The air gaps when the ring is centered are 0.040 inch from pole to ring and 0.40 inch from ring to magnet. It is quite possible that a misalignment of less than 0.005 inch would be difficult to maintain on a production machine. In this system it is essential that the phase of $e_v$ can be changed the whole 360 degrees with respect to $e_r$ at constant magnitude. Also, voltage $e_v$ should be constant with given unbalance and its phase with respect to $e_r$ should always indicate true position of unbalance. The curve on figure 12 shows, experimentally, the effect of misalignment on sensitivity. It is noted that the misalignment may be as great as 15 per cent before the calibration is affected more than 1 per cent.

## Sensitivity

Earlier in this paper some indication of required accuracy in balancing was given. Measurements show that it is desirable to detect and correct an unbalance of the order of 0.00001 ounce inch. This unbalance produces a very slight vibration in the frame. The initial unbalance is of the order of 0.001 ounce inch. The maximum unbalance produces about 2 millivolts which reduces to roughly 20 microvolts for the minimum reading. The internal impedance of the pickup is about 1,400 ohms, so the power output is very low. A high-gain amplifier is necessary to produce the power necessary for even a sensitive meter. A fairly simple, 3-stage full a-c operated amplifier can be made to give satisfactory results.

An attenuator to serve as a meter multiplier is necessary to allow the use of the meter on full scale on minimum signal for phasing purposes. The signal may change in the ratio of 100 to 1 or more, so changing of meter scale is mandatory.

Figure 13 shows the very linear relation that exists between magnitude of unbalance and voltage output. In balancing the rotor, the magnitude and position of unbalance is observed and recorded for both ends of the rotor. Then the 2 ends of the rotor are drilled the indicated depth at their proper respective positions. All weight correction is accomplished by drilling. Figure 14 is a calibration curve of drill depth against voltage. The nonlinear characteristic is due to the conical shape of the drill point.

It would be very advantageous to balance the rotor perfectly in one reading. Consideration shows the impossibility of this. First, the unbalance indication must

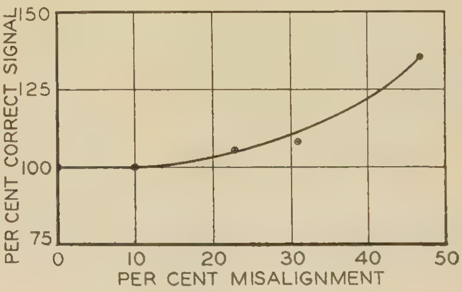



Figure 12. Effect of misalignment on calibration

be reduced from 2 millivolts down to less than 10 microvolts, a ratio of 200 to 1. Secondly measuring instruments have inherent errors that in practice cannot be eliminated. A voltmeter is never accurate to better than 1 per cent. Taking the combined inaccuracies of amplifier attenuators, etc., the errors will be not less than 5 per cent. If the error is 5 per cent, the initial unbalance indication can be reduced by a ratio of 100 to 5 or from 2 millivolts to 100 microvolts. Experience shows that 3 "shots" usually are required at each end. It can be shown that a balance in 3 readings can be obtained with over-all calibration errors of as much as 10 per cent.

## Production Balancing

Figure 15 shows the form of the machine that is replacing older methods in production balancing. It is designed especially for speedy manipulation in the factory. The main features of this device are (1) duplicate pickups, one at the top and one underneath and (2) one set of supporting springs for each correction plane. The springs are controlled by cams operated simultaneously by a handwheel for the purpose of changing the support from one correction plane to the other. When the support is shifted to the top springs, a switch operates automatically to connect the bottom pickup to the circuit and vice versa. The 3-sided rotor frame is designed to permit quick insertion or removal of the rotor without damage to the pivots.

This system is the only one to our knowledge which provides the extreme sensitivity required in balancing airplane instrument gyroscope rotors without depending on superkeen perceptions in the operator. Also, the speed of balancing is several times faster than the most skilled operator could make with former methods. Rejections due to defective rotor balancing are reduced from nearly 50 per cent to zero because the machine, in largely removing the human element in the measurements, can obtain exactly the same degree of balance on every unit.

Another valuable feature of the machine, which has not yet been thoroughly investigated, is its use as a "stethoscope" for checking vibrations caused by sources other than unbalance. In this use, the fixed band-pass filter is taken out and replaced by a "wave analyzer." Such an instrument is shown in figure 11. Frequency spectrums similar to the one shown in figure 7 can then be taken. This information is important in the study of ball bearings, case resonances, high-speed gyroscopic nutations, etc. It has enabled us to measure effect of looseness and out of balance in ball-bearing retainers. All of the possible uses for such a machine have obviously not been explored. However, they appear to be numerous and, no doubt, several other interesting applications will follow.

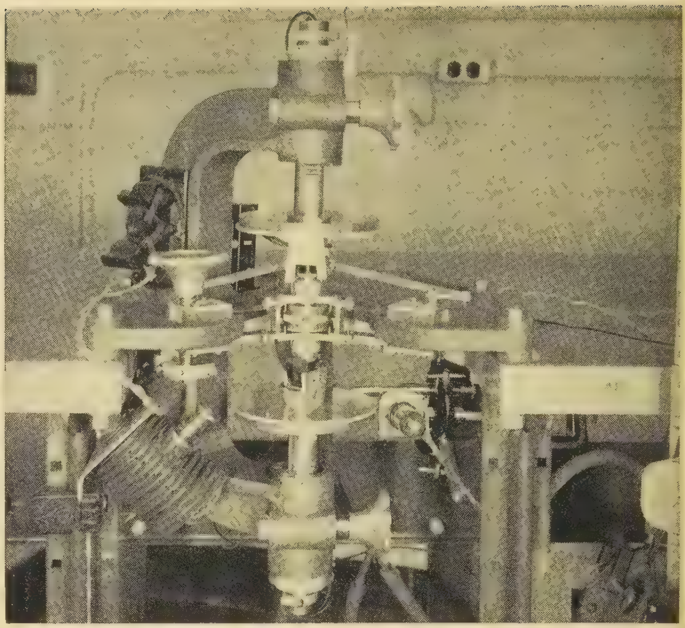


Figure 15. Production rotor balancing machine

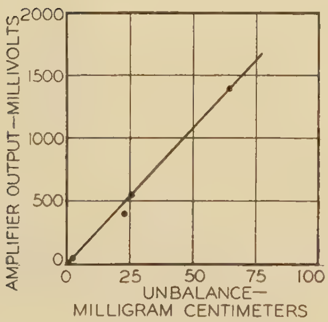



Figure 13. Unbalance versus output of ring-type pickup

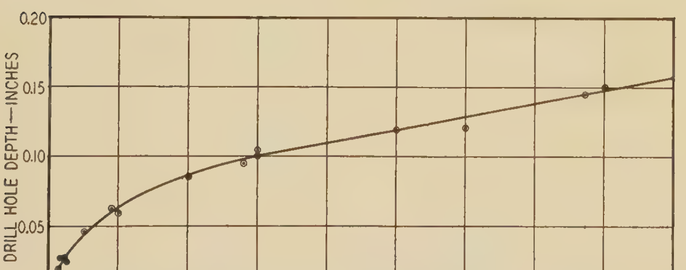



Figure 14. Calibration curve of output versus drill depth for weight correction

## References


1. Dynamic Balance, Akimoff. ASME *Transactions*, 38, 1916.
2. Recent Developments in Balancing Machines, Soderberg. ASME *Transactions*, 45, 1923.
3. Turbine Vibration and Balancing, Rathbone. ASME *Transactions*, 51, 1929.
4. A New Type of Dynamic Balancing Machine, Thearle. ASME *Transactions*, 1932.
5. Dynamic Balancing of Rotating Machinery in the Field, Thearle. ASME *Transactions*, 1934.
6. A Rapid Method for Determining and Correcting Unbalance, Rushing. *Instruments*, September 1935.
7. Balancing Rotors by Electrical Networks, Baker and Rushing. *Journal* of the Franklin Institute, August 1936.
8. Vibration in Industry, J. P. Den Hartog. *Journal of Applied Physics*, February 1937.
9. Vibration Problems in Engineering, Timoshenko.
10. Mechanical Vibrations, J. P. Den Hartog.

# The Vibration Isolation of Machinery

By L. H. HANSEL

THE GENERAL purpose of isolating machinery is to reduce the amount of noise and vibration transmitted to the structure in which the machine is housed, or to adjoining structures. The general subject of isolation and isolation materials is receiving increasing attention with the tendency to speed up machinery. Machine designers recognize the fact that increased speed has resulted in troublesome vibration problems that previously had not reached "nuisance" or "damage" levels. The great majority of manufacturing tools are inherently unbalanced. To design a ba'anced drop hammer, loom, punch press or automatic machine is not feasible. In such cases the use of isolation material becomes a necessity.

Unfortunately, in many instances, isolation has been tried and the desired results have not been attained. These failures have been generally caused by a lack of understanding as to the principle of isolation and the absence of practical knowledge as to how and where the material should be installed.

The first principle of isolation is that the natural frequency of the machine on its isolation must be considerably less than the operating vibration frequency of the machine. As an example, let us assume that we have a machine which gives rise to vertical vibrations of frequency 30 per second. The machine weighs 1,600 pounds and is to be supported upon 4 equal springs. Furthermore, we desire to reduce the vibrations transmitted to the surroundings to $^1/_9$ of the value when springs are not used. If $k$ is the "stiffness coefficient" of the 4 springs, $n$ the frequency, $A_1$ the amplitude of transmitted vibration without the springs, and $A_2$ is the transmitted vibration with the springs, then

$$\frac{A_2}{A_1} = \frac{k}{4\pi^2 n^2 \dfrac{w}{g} - k} \tag{1}$$

substituting

$$\frac{1}{9} = \frac{k}{4\pi^2 \times 900 \dfrac{1600}{32.2} - k}$$

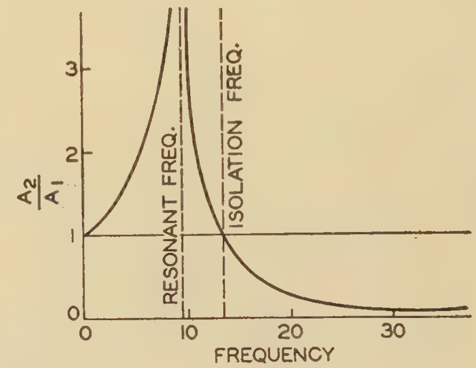
and $k = 176{,}000$ pounds per foot.

For one spring the stiffness coefficient is 44,000 pounds per foot or 3,660 pounds per inch. Four springs each giving a deflection of one inch for a 3,660-pound load solve the requirements.

It is noted, that the stiffness coefficient is an important property of an isolator. From equation (1) we can calculate what isolation will be obtained at frequencies other than the operating frequency of 30 vibrations per second. When $k = 4\pi^2 n^2\, w/g$, $A_2/A_1$ becomes theoretically infinite. The transmitted vibrations at this frequency are very much higher with the springs than without them. This occurs at a frequency of 9.5 vibrations per second. At a frequency of 12.4 vibrations per second $A_2 = A_1$, and the transmitted vibrations are the same with the springs as without them. This frequency is called the "isolating frequency." A plot of the calculated values of $A_2/A_1$ for various frequencies is shown in figure 1.

Examination of this curve shows that below the isolating frequency (where $A_2/A = 1.0$) the transmitted vibrations are larger with the spring isolators than without them. The system only becomes effective at frequencies higher than 12.4 vibrations per second.

Figure 1




If the springs are stiffened the natural and isolating frequencies become higher, and consequently their effectiveness at the operating frequency of 30 per second is lessened. If the springs are reduced in stiffness the situation is improved. Questions of stability will determine what minumum stiffness coefficient is permissible.

The resonance peak is undesirable in the majority of cases. During the starting and stopping of the machine the transmitted vibrations are large and, in addition, the machine on the springs oscillates through a very large amplitude, both of which are objectionable. To remedy these difficulties it is desirable that the isolation material possess "damping" qualities.

Damping has 2 principle effects. It greatly reduces the height of the resonance peak, but the installation is less effective than isolation with no damping at frequencies higher than the isolation frequency. The curves of figure 2 show a material with little damping and one with considerable damping.

Experience has shown that the improvement obtained at frequencies lower than the isolation frequency with the

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted April 8, 1937; released for publication April 29, 1937.

L. H. HANSEL is vice-president and treasurer of The Felters Company, Inc., Boston, Mass.

material with appreciable damping properties is of great practical importance.

If the material has appreciable damping qualities the $A_2/A_1$ equation 1 becomes:

$$\frac{A_2}{A_1} = \sqrt{\frac{r^2 + \frac{k^2}{4\pi^2 n^2}}{r^2 + \left(2\pi n \frac{w}{g} - \frac{k}{2\pi n}\right)^2}} \qquad (2)$$

Where $r$ is the damping constant.

This constant is measured by taking a record of the damping curve. One method of doing this is illustrated in figure 3.

The test piece is loaded with 2 suitably sized weights. A small stylus bears on the top bearing plate. Any motion of the isolation material causes the mirror to move about its axis and a beam of light to move across the slit of a constant film speed moving picture camera. The lower weight is suddenly moved and a record of the oscillations is made on the film. From measurements on the damping record the value of $r$ can be evaluated.

Control of materials and manufacturing processes makes it possible to make felts covering a very wide range

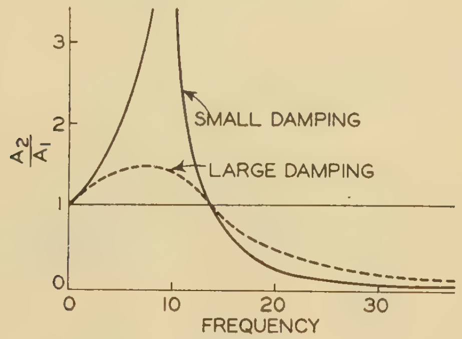



**Figure 2**

of stiffness coefficients. For example, felts can be made which are suitable for loadings from 2 to 500 pounds per square inch. In determining the properties of these load-deflection curves were measured together with the damping or "resistance" coefficients. Curves similar to that shown in figure 4 were then calculated.

These curves have been checked at numerous points by measuring transmitted vibrations in the following manner.

The vibrations of an eccentrically loaded motor were measured with no isolation, thus giving the value of $A_1$. The test material was installed at the desired loading and the vibrations transmitted to the surroundings were again measured, thus giving the value of $A_2$. The readings so made served as a direct check upon the determination of $A_2/A_1$ by means of equation 2.

For purely rotative devices such as electric motors, the frequency to be isolated is the speed in revolutions per second. The frequency to be isolated for more complex machines is not so easily determined. The satisfactory method is to obtain a photographic record of the vibrations. There are 3 general types of instruments used: displacement recorders, velocity recorders, and accelerographs. Each gives a different recorder, and what is measured as the predominate frequency of the frequency giving the biggest displacement on the record is not necessarly the same for the 3 instruments. As an illustration of this, let us assume that a record similar to figure 6a is obtained with some type of velocity recorder. If a record is now made with an accelerograph it appears as in figure 6b. An examination of the 2 records discloses that the frequency to be isolated as determined by the accelerograph

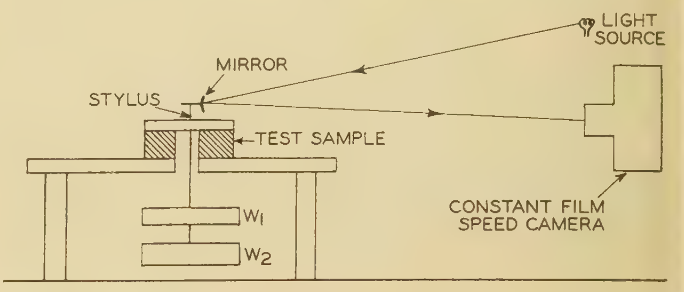
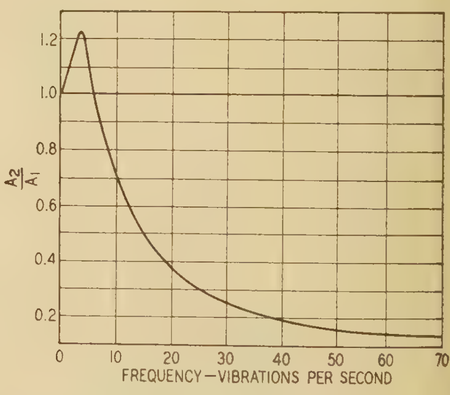



**Figure 3**

is 4 times as high as is determined by the velocity recorder. A record of the same vibrations taken on a displacement recorder would give a much smoother curve than 6a, and the slight irregularities of 6a would be much smaller on the displacement record.

The only case where records from the 3 instruments would be similar is when the vibratory motion is simple harmonic, such as an unbalanced rotor. The question then arises as to which of the 3 should be used in a determination of the frequency to be isolated, where the machine

**Figure 4**




is more complex. Since we are interested in damage to the structure or annoyance to persons, the measurement which best measures damage or annoyance is the proper one to use. Since acceleration is proportional to unbalanced force it seems reasonable to accept acceleration as the best measure of damage. Through evidence collected by seismologists and engineers acceleration is a better measure of structural damage than velocity or displacement.

Experiments have been made in order to establish a unit of "nuisance level" of vibrations, that level at which people term a vibration an annoyance. Neither acceleration, velocity nor displacement are satisfactory as a unit. When the vibrations are accompanied by noise, it very often happens that eliminating the noise results in the opinion that the vibration difficulty has been overcome. What one person calls an objectionable vibration, another does not, so that the establishment of a satisfactory

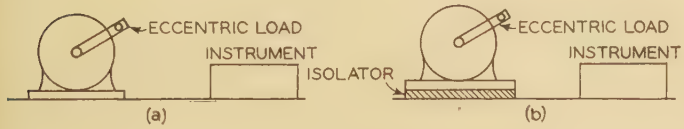



Figure 5

nuisance level does not seem possible. Such being the case and accepting the fact that acceleration is the best measure of damage, the accelerograph is preferable to the velocity or displacement recording instruments.

It is well to examine the more practical aspects of vibration isolation with the idea of pointing out the more common errors made in installation. The most common of these is "bridging." Many installations are found in the field where the use of holding-down bolts makes the application useless.

A "bridged" isolator is shown in figure 7*a*. Here the holding-down bolt or lag screw is rigidly connected to the

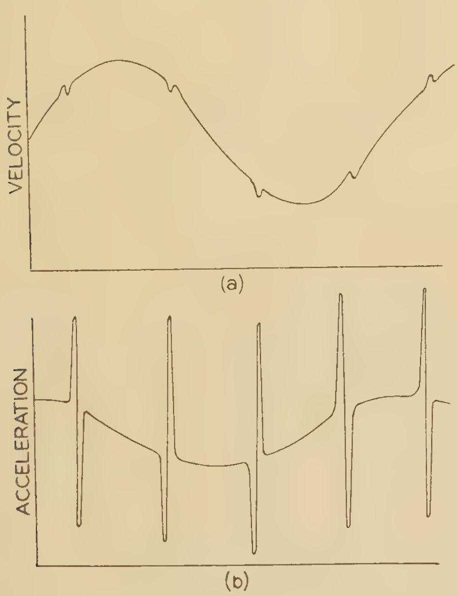



Figure 6

machine foot and to the floor, and offers a direct path for the transmission of vibration. Where holding-down bolts are necessary the installation can be made as in figure 7*b*, where no direct path for the transmission of vibrations is available, except through the isolating material. In such arrangements clearance must be provided between the bolt and the machine footing. The lower pad takes the sum of bolt load plus machine load, and the upper pad, the bolt load. Generally the bolt load is in excess of the mass load of the machine. The efficiency of the isolation is determined by the mass load and not by the bolt load. Consequently, it is necessary to use a material which is capable of taking the bolt plus machine load without deterioration. This is necessarily a stiffer material than one which would have to withstand the machine load alone, and isolation efficiency is sacrificed. Many machines have to be bolted down.

It has been found that a great many others which are ordinarily bolted do not require bolts provided the pad can be cemented to the foot of the machine and to the floor. It has been found, for example, that a satisfactory

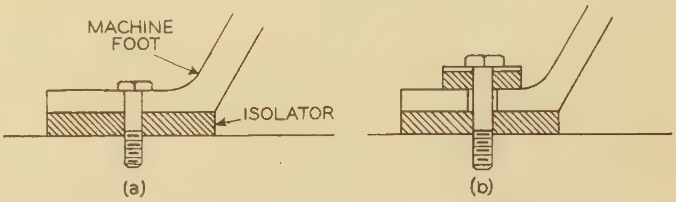
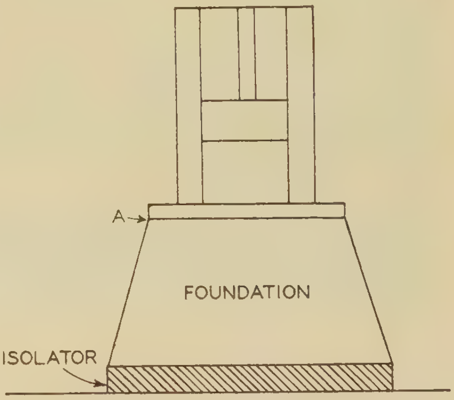



Figure 7

and preferable method of mounting looms is by eliminating the bolts or lag screws, and cementing the pad. The loom stays fixed in its location, the mass loading on the pad is correct, and the cost of the pads themselves is largely offset by the saving in the cost of installing the lag screws or bolts.

In connection with the loom problem, it is interesting to note that many loom sheds have very large horizontal

Figure 8




vibrations. This occurs when a number of looms get in phase and the disturbing force is high. The natural frequency of the structure in which the looms are housed is often in the neighborhood of the loom speed so that a condition approaching the resonance peak exists. With the advent of increased loom speeds it is probable that in many cases the loom speed will more nearly agree with the natural frequency of the structure and the vibration situation will be very much worse.

One of the most troublesome of vibration transmitting

machines is the drop hammer. Unisolated drop hammers give rise to vibration which are transmitted long distances and seriously affect adjoining property owners. To isolate a hammer already installed is an expensive job to do properly. The machine must be taken down and the isolation material installed underneath the foundation as in figure 8.

Placing the isolation material directly under the hammer (at $A$) will result in a loss of hammer efficiency. The material must withstand the mass loads of machine and foundation, and be capable of long life under the effect of the hammer blows. The magnitude of the blow is difficult to determine since it depends upon the size of the hammer, the drop and the temperature and nature of the work. However, on large hammers the impact blow is of the order of 2,000,000 pounds.

Punch presses are serious offenders. The record shown in figure 9*a* is of an unisolated punch press. The film speed of this record was 3.5 inches per second. The calibration of the instrument showed that a displacement of the light source of 0.23 inches from its median position indicated an acceleration of 10 per cent of gravity. The blows occur about every 1.3 seconds. This, however, is not the frequency which has to be isolated. The frequency of vibration at the impact is of the order of 100 vibrations per second. Figure 9*b* shows the effect of installing isolation material.

Machine footings are of all sizes and shapes. The loading on the footings cover a wide range. In the use of pad materials we can vary the thickness and area of the pad to get the desired load-deflection conditions. Furthermore if the material itself can be manufactured to get various load-deflection properties for a given thickness, all conditions of loading met within practice can be properly treated.

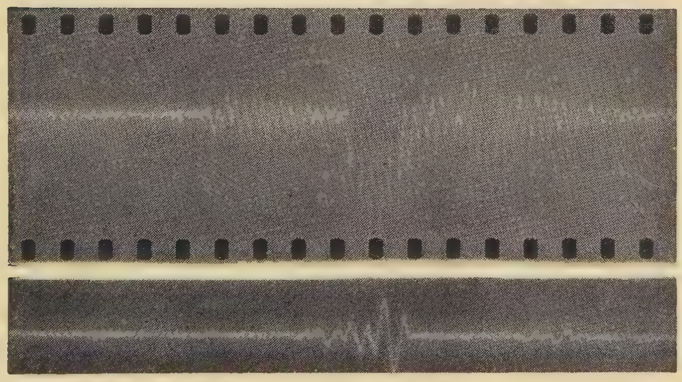
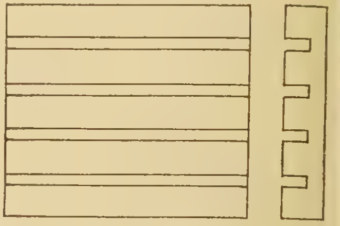


Figure 9a (top) Figure 9b (bottom)

We have previously talked almost entirely of vertical vibrations. These are greater sources of disturbance ordinarily than horizontal vibrations. Where horizontal vibrations are large, then the isolator must be installed with the viewpoint of simultaneously correcting for both vertical and horizontal vibration. This may be accomplished by grooving or slotting the pad in the proper direction, as shown in figure 10.

Figure 10



The pad is placed under the machine so that the direction of maximum horizontal vibrations is perpendicular to the slots. Various other arrangements of grooving or slotting are possible.

Ship vibrations are exceedingly troublesome. These are caused by machinery within the ship and by disturbances originating at the propeller. Very little has been done in isolating the machinery of a ship. Proper alignment of shafting and the demand for stability during the rolling and tossing of the ship are additional demands which must be met by the isolation installation. Recent work on smaller pleasure cruisers has shown, however, that annoying vibrations can be greatly reduced by isolation of the main motor and a suitable flexible coupling in the propeller shaft.

Any isolation material to be effective allows the machine more freedom of motion than an installation with no isolation. In advertising one frequently sees charts of the vibrations of an isolated machine, compared with the vibrations of the surroundings. Such a comparison is unfair. The only fair comparison is a record of the vibrations of the surroundings due to an unisolated machine, as compared to an isolated one operating under the same conditions.

Structurally borne noises are a source of disturbance frequently found in factories particularly where offices are located adjacent to manufacturing operations. Correction can be made by isolating the disturbing machines. Quite frequently attempt has been made to quiet the office by the installation of sound absorbing material on the walls or ceilings. These applications do not give the desired results. The sound absorbing material is effective in correcting air borne disturbances. Those noises which are structurally borne are best handled by attacking the problem as near the source of disturbance as possible and installing proper machine isolation.

## References

1. Theoretical Seismology (a book), Sohon, John Wiley & Sons, Inc., New York, N. Y.

2. Mechanical Vibrations (a book), Hartog. McGraw-Hill Book Company, Inc., New York, N. Y.

3. Architectural Acoustics (a book), Knudsen. McGraw-Hill Book Company, Inc., New York, N. Y.

4. Noise and Vibration Engineering (a book), Slocum, D. Van Nostrand Company, Inc., New York, N. Y.

# New Oil-Filled Cable Lines in Chicago

By HERMAN HALPERIN
MEMBER AIEE

G. B. SHANKLIN
MEMBER AIEE

Several recent developments in cable, joints, reservoir layout, and installation are incorporated in the 4 66-kv single-conductor oil-filled underground lines being installed in Chicago in 1936–37. The main results are economies and simplification. The emergency ratings of the lines are 115,000 kva in summer and 135,000 kva in winter.

During 1936 and 1937 the Commonwealth Edison Company is installing in Chicago 4 66-kv underground lines consisting of about 100 miles of single-conductor oil-filled cable. A summary of developments made in connection with these lines, which have a nominal rating of 100,000 kva, is given in this paper. The main objectives were to simplify oil-filled cable systems and make them adaptable for installation in standard underground conduits and manholes, and to reduce costs.

The principal results obtained as compared with previous oil-filled cable installations were as follows:

1. Ten or 12 per cent reduction in insulation thicknesses.
2. Substitution of copper-bearing lead sheath for more expensive 2 per cent tin sheath.
3. Smaller, simpler, and more economical stop and feeder joints.
4. Use of simpler and more economical reservoirs, and development of staggered system of oil feed.
5. Simplified layout, and development of joints and reservoirs that could all be installed in standard manholes, instead of requiring special manholes or towers.

The changes made during this development work in insulation thicknesses, kind of lead sheath, joint design, reservoir layout, etc., have been adopted in principle for oil-filled cable work in the United States. Employing these and other new ideas developed during the past 10 years, including sheath loss elimination, the cost of an oil-filled 132-kv line to have the same carrying capacity as the 1926–27 Chicago line[1] would be only 55 per cent of the cost of the actual installation.

## Economics

These 4 oil-filled lines are additions to a 66-kv system which connects 5 generating stations and 2 distribution stations, power through transformers being fed in at some stations and being taken out at other stations. See figure 1. The system is divided into 2 parts throughout the city with bus tie switches available at the terminal for special use.

The original 66-kv lines installed in 1926 to 1931 consist of 280 miles of 750,000-circular-mil cable of the ordinary solid type with 1,000,000-circular-mil cable in the warmer conduits, and the carrying capacities in the summer for normal and emergency conditions are, respectively, 52,500 and 56,000 kva. System growth warranted the installation of lines having an emergency rating in the middle of the summer of 115,000 kva. As compared to the former standard lines, these new lines result in a saving of about 25 per cent in cost per kva of carrying capacity and in a substantial saving in cost and space for the terminal facilities.

Satisfactory cables of both the ordinary and oil-filled type were available. Early in 1933, 2,100,000-circular-mil segmental-conductor cable of the ordinary type was used for a 9,000-foot line between Calumet and State Line stations because of a 10 per cent advantage in costs over an oil-filled cable installation for the same copper temperature. For the 1936–37 lines, oil-filled cable was used mainly because of the larger emergency carrying capacity and lower annual charges per kilovolt-ampere. Figure 2 illustrates the 3 main types of 66-kv cable that have been used in Chicago.

From the standpoint of over-all economy as well as from the need to avoid overcrowding principal routes for conduits between stations, it was desirable to use existing conduits for the new lines as much as possible; this has been done for 60 per cent of the oil-filled 66-kv cable installed. It was necessary to limit the average losses of the new lines in order to avoid overheating the existing cables in the conduits. This limitation required the use of 2,100,000-circular-mil conductors for either the oil-filled or the ordinary type of cable in most of the conduits, and 2,800,000- or 2,600,000-circular-mil conductors, respectively, in the congested conduits near stations. Studies and experience with the first line, however, showed that with 2,100,000-circular-mil oil-filled cable it was possible to allow its temperature to be a few degrees above the maximum permissible for cable of the ordinary type. As a result, only 4 per cent of the length of 4 lines will consist of 2,800,000-circular-mil cable, whereas 15 per cent of the length would have had 2,600,000-circular-mil conductor if ordinary cable were used. The oil-filled cable had a hollow core 0.69 inch in diameter, while the ordinary cable considered had a conductor consisting of 3 segments to obtain reduced copper losses. For the emergency ratings of the oil-filled cable, this meant copper temperatures in the warmer conduits about 10 degrees centigrade below the guaranteed maximum value of 75 degrees centigrade.

When the peak loading necessitated by emergency system conditions begins to approach the maximum rating of

A paper recommended for publication by the AIEE committee on power transmission and distribution. Manuscript submitted March 29, 1937; released for publication April 24, 1937.

Herman Halperin is in the engineering department of the Commonwealth Edison Company, Chicago, Ill.; G. B. Shanklin is in the central station department of the General Electric Company, Schenectady, N. Y.

1. For all numbered references see list at end of paper.

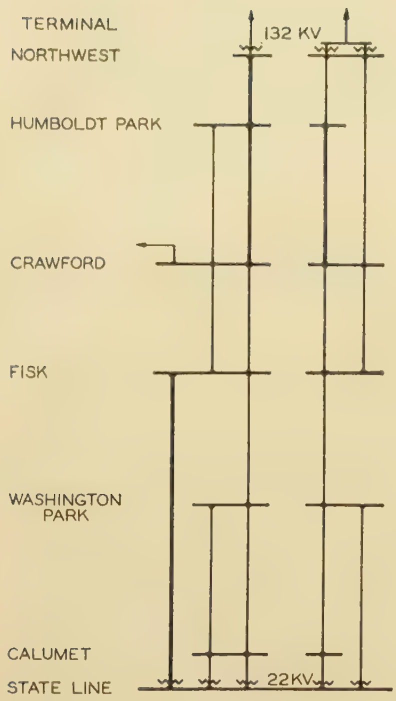



**Figure 1. Underground system for 66 kv in Chicago at end of 1937**

Heavy lines represent oil-filled cable; light lines represent cable of ordinary type

Drawing is practically to scale; State Line-Fisk line is 15 miles long

All terminals are generating stations except Humboldt Park and Washington Park

a line, then an additional line must be installed, in spite of the fact that the carrying capacity of the existing line under normal conditions may be adequate. The emergency ratings for the solid type cable were limited not only by the maximum allowable specification temperature of 60 degrees centigrade, but also by operating experience which indicated that the use of large temperature ranges would create undue internal pressures and sheath expansion. Based on operating experience and measurements of internal pressures on 750,000- and 2,100,000-circular-mil cables in service, and taking the expected normal loading into account, the maximum allowable daily range in copper temperature during emergency loading of the 2,100,000-circular-mil solid-type cable lines considered (656 mils of insulation and 156 mils of sheath) appeared to be about 15 degrees centigrade in summer and 17 in winter. With such daily temperature changes, it was expected that the internal cable pressures might be 50 or 75 pounds per square inch, even after a line had been in service and had experienced some sheath stretching.

The emergency rating for the oil-filled cable in the summertime was limited by the temperature requirements for other cables in the same conduit, while for winter conditions it was determined by what was considered the limit of possible future requirements. The winter rating could have been made larger by the installation of a few more reservoirs.

The relative costs for the 2 types of 2,100,000-circular-mil cable, shown in table I, were determined on the basis (1) of bid prices obtained in the fall of 1935 for cable and accessories and (2) of the experience of the Commonwealth Edison Company in installing, maintaining, and loading somewhat similar lines. Incidentally, the estimated cost of the first line installed differed from the actual cost by only 1 per cent. The costs shown include indirect or overhead costs such as engineering, storeroom, superintendence, and interest during construction.

The total annual charges for the 2 types of cable were almost the same. Due to the higher emergency carrying capacities of the oil-filled cable, however, the annual charges per kilovolt-ampere of carrying capacity were about 9 per cent less for the oil-filled system in summer, and 18 per cent less in winter. Oil-filled cable was, therefore, selected for the new lines. Later experience showed that the saving with oil-filled cable was slightly greater than originally expected.

To figure the fixed charges on the investment, the authors used the same rate of depreciation for both types of cable, although the use of a lower rate for oil-filled cable would have been defensible. The annual charge for "maintenance" includes the cost of (*a*) repairing oil leaks, (*b*) routine inspection of cable in manholes for sheath cracks and checking of reservoirs, and (*c*) the cost of repairing failures. The assumed rate of failures for oil-filled cable was one cable or joint burnout per 100 miles of cable per year, with no anticipated failures.

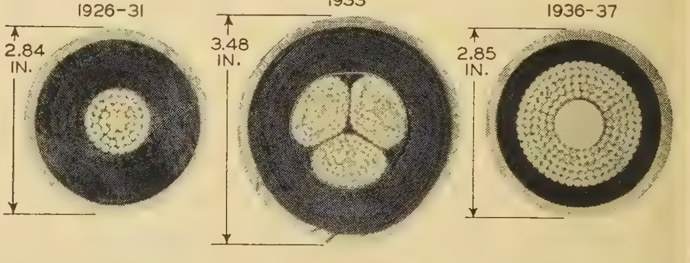



**Figure 2. Changes in 66-kv cables in Chicago**

| | 1926–31 | 1933 | 1936–37 |
|---|---|---|---|
| Type of insulation | Ordinary | Ordinary | Oil-filled |
| Insulation thickness, mils | 750 | 688 | 315 |
| Conductor size, circular mils | 750,000 | 2,100,000 | 2,100,000 |
| Maximum summer rating, kva | 56,000 | 105,000 | 115,000 |

One factor that was hard to evaluate for solid type cable was the effect of its maximum diameters being about 3.4 and 3.6 inches, respectively, for its 2 sizes. A slight amount of conduit used had $3^1/_2$-inch ducts, which would not have been usable. Experience showed also that some of the standard 4-inch ducts would have had to be rebuilt for the 2,100,000-circular-mil cable and probably the 2,600,000-circular-mil cable could not have been installed in most of these ducts.

## Insulation

The 1934 edition of the AEIC cable specifications gives an insulation thickness of 350 mils for oil-filled cable having a rating of 69 kv, except that above 2,000,000 circular mils the cable was to have 25 mils more of insulation. The manufacturers first thought that it would be satisfactory to use a thickness of 350 mils for the 2,100,000-circular-mil cable, but that for the 2,800,000-circular-mil cable the extra thickness would be necessary. The thickness used on the only oil-filled 69-kv cable previously

made in this country (in 1930 for Cincinnati) was 406 mils. After some discussion of American and European experience, the thicknesses agreed upon were 315 mils and 330 mils, respectively, for the 2 Chicago sizes.

The Commonwealth Edison Company has been making periodic measurements of the power factors of 2 short oil-filled 132-kv lines put in service early in 1930. The insulation thickness is 719 mils. Figure 3 shows that the power factors at 15 degrees centigrade and operating voltage have remained practically constant, which indicates that the insulation has been quite stable.

About 8 years ago, this utility installed 4 1,000-foot lengths of experimental cable which were tapped to an overhead 132-kv line and were subjected also to heating by means of current transformers. The insulation thicknesses ranged from 386 to 526 mils. For 2 years these cables were subjected to daily load cycles with temperatures as high as 75 degrees centigrade. Subsequently, the heating has been continuous to temperatures as high as 85 degrees centigrade, except that occasionally the cables were allowed to cool for power factor measurements. The results of these tests have shown the following:

(*a*) The voltage did not appear to cause any deterioration of the insulation. The maximum stresses ranged from 188 to 250 volts per mil.

(*b*) Temperatures up to about 80 degrees centigrade did not appear to cause any deterioration of the insulation.

(*c*) The changes which have been observed in some of these cables have been of a type that accompanies chemical reactions. If the insulating oil becomes oxidized, chemical action with the metals may result, causing the oil in the cable to darken in color and to increase in power factor, although its dielectric strength remains practically unchanged.

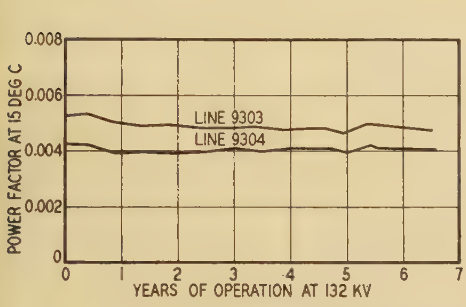



**Figure 3. Power factor of the insulation of 2 commercial oil-filled 132-kv lines**

In 1932 it was necessary to remove from a commercial line in Chicago 3,000 feet of 132-kv oil-filled cable that had been installed in 1930, because of deterioration of this kind resulting from oxidation of the oil. The dielectric losses of the cable insulation had increased so much that the cable was fully heated when carrying almost no load. Although extensive investigations were conducted over a period of several years, the origin of this oxidation was not discovered other than that it was due either to overheating of the oil or to contamination of the cable, or both.

This experience indicated again the necessity of preventing overheating of the oil and preventing entrance of air into the cable. Now extensive tests of core oil from the completed cable at the factory, including a power factor or resistance test at 100 degrees centigrade of a sample of oil from each length, and tests of oil used in the field, are made as a routine procedure. Also, as discussed later, special precautions are taken in the field.

The experience with the experimental cables indicates that within limits the thickness of insulation was of little or no importance in connection with the chemical action. Results of tests of power factor, acidity, etc., obtained on samples of core oil removed periodically from the 4 commercial oil-filled 132-kv lines in Chicago have indicated that an initial period of deterioration occurred as a result of minute impurities in the installed line; but this core oil deterioration has caused no perceptible increase in dielectric losses of the cable as a whole. The initial reaction of impurities appears to have taken about 2 years.

In view of all these considerations and of the successful operation of large amounts of oil-filled cable in Chicago and elsewhere, reductions in insulation thicknesses were obviously warranted. The recommended thicknesses are now 315 and 560 mils of insulation for

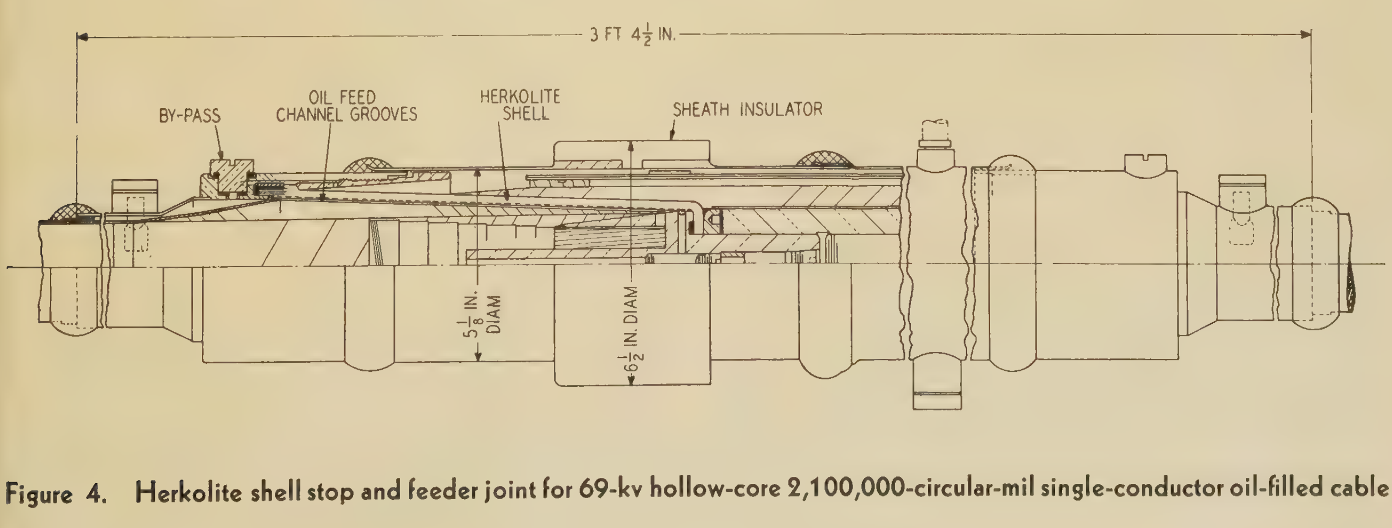



**Figure 4. Herkolite shell stop and feeder joint for 69-kv hollow-core 2,100,000-circular-mil single-conductor oil-filled cable**

cable rated at 69 and 138 kv, respectively, except that slight increases are made for extra-large conductors.

The indications are that, perhaps, even smaller thicknesses may be used from the standpoint of steady voltages, but that further reductions will be retarded by the limitation of impulse strength of the insulation to withstand surges incidental to failures, switching, or lightning.

## Lead Sheath

Until recently, oil-filled cables in the United States were furnished with 2 per cent tin in the lead sheath in order that the cable would present a hard surface during pulling to minimize abrasion. Improvements in the installation of conduit and in the mandreling of ducts to remove small pebbles and other obstructions have made a special hard surface sheathing unnecessary.

Research done at the University of Illinois for the Utilities Research Commission showed that the rate of creep of copper-bearing sheath under tension was usually considerably less than the rate of creep of other sheaths in normal use including 2 per cent tin-lead sheath. The rate of creep is important because oil-filled cables operate continuously with positive internal pressures. Copper-bearing lead may be obtained without any extra expense at present as ASTM grade II lead, or as a mixture of highly refined grade I or III lead and about 0.055 per cent copper having a pure lead content of at least 99.85 per cent.

It was, therefore, decided to use copper-bearing sheath at a saving of almost 5 per cent in the cost of the cable.

In order to prevent excessive expansion of the sheath during the normal life of oil-filled cable, the tensile stress on the sheath has been usually limited to 120 or 150 pounds per square inch, based on the nominal sheath thickness. This corresponds to an internal pressure of 12 or 15 pounds per square inch for the Chicago cables. Important improvements have been made in the manufacture of cable sheaths during the past few years. Better uniformity in sheath thickness and in exclusion of nonmetallic impurities has resulted. It seemed, therefore, especially with copper-bearing lead, that it was feasible to increase the maximum allowable internal pressure with variable pressure reservoirs to 17 pounds per square inch. This was particularly safe for the new lines, since the maximum operating pressures will usually be 8 or 10 pounds. The sheath thicknesses used were $^{9}/_{64}$ and $^{10}/_{64}$ inch, respectively, for the 2,100,000- and 2,800,000-circular-mil cables.

Where differences in elevation give a considerable hydrostatic head of oil within the cable, a double sheath is used, having 2 parallel copper ribbons wound between the 2 sheaths to reinforce it. Such lengths are being installed in Chicago in tunnels under the rivers and where the cable rises to upper levels in a distributing station. The maximum internal pressure in these lengths is 30 pounds.

## Design and Manufacture of Cable

The design and manufacture of oil-filled cable were rather fully developed by the time the first of these 66-kv lines was planned. Consequently, the general process of manufacture did not differ materially from past practice. New features introduced were for purposes of further reducing cost or giving additional assurance of uniformity and freedom from impurities. The cable was furnished by 4 American manufacturers.

The conductor design was of the conventional hollow-core type with a supporting spiral of steel strip. The reduction in insulation thickness has already been discussed. The inner third (approximate) of the insulation consisted of high-density paper tape. The rest was of paper of more conventional density. Previous study had shown these proportions to give a good balance, from both a technical and a cost standpoint. The dielectric power factor, ionization factor, and time of impregnation treatment are not appreciably affected, as they would be with too much high-density paper; and, in return, there is gain in the way of mechanically stronger foundation tapes and increased impulse strength (10 to 15 per cent).

Thoroughly washed wood-pulp paper was used, and a system of testing all paper to assure uniformity and freedom from impurities was followed. Likewise, a system of handling and checking the impregnating oil for uniformity before and after treatment was closely followed. Such oil was used only once, and any oil exposed to the atmosphere or to excessive heat in sealing the cable ends was flushed out and discarded.

The final electrical and physical tests to which every reel length is subjected leave little possibility of nonuniformity. These tests consist chiefly of dielectric power factor and ionization measurements on finished lengths, chemical, electrical, and physical tests on withdrawn samples of core oil, a continuous oil pressure leakage test, and an expulsion test for detection of trapped air.

The change to copper-bearing lead sheath and the

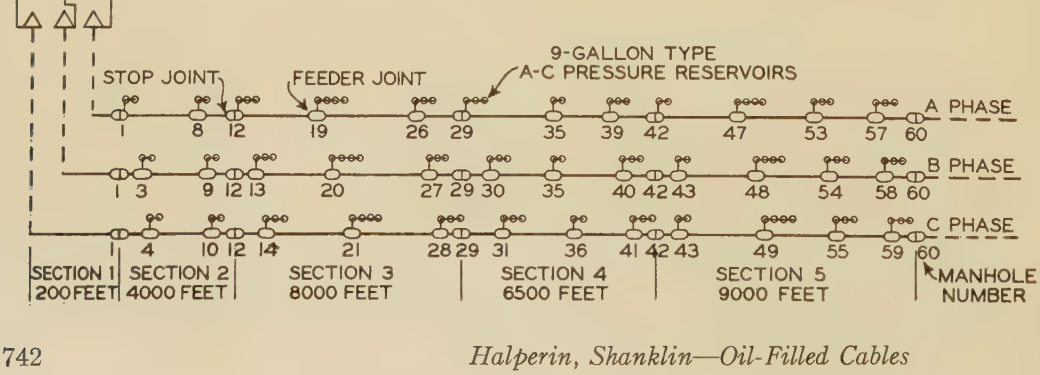
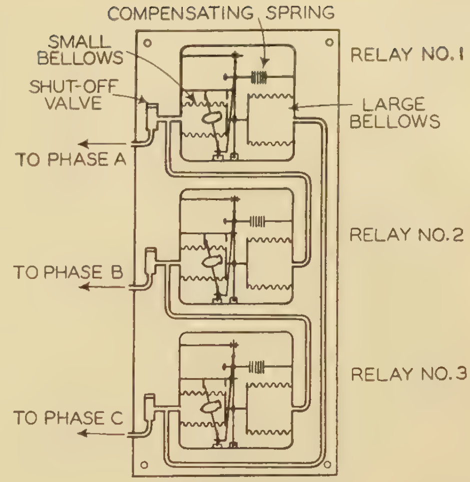



**Figure 5. Typical layout of oil feed system**

Distance between manholes is assumed to average about 500 feet, except adjacent to terminals

factory improvements leading toward a more uniform sheath have already been mentioned. Trouble with single-wall lead sheath, limited to low working pressure (15 pounds per square inch), has been almost negligible in the past. This, of course, is due to the exact control of pressure in oil-filled cable. With sheath of improved quality, practically entire absence of sheath trouble due to working pressure strains may be reasonably expected.

**Figure 7. Diagram of phase differential alarm relays arranged for connection to 3 phases**




## Design and Manufacture of Accessories

Some general comments on accessories will be given before describing some of them in detail. These high-voltage accessories consist of a surprisingly large number of parts; and, since most of them must be assembled directly in the field, rather than in the factory, it is much more difficult than generally supposed to assure that these parts will always fit together exactly, in the simplest possible way and in minimum time. Perfection of these details requires constant close co-operation between the manufacturer and user. All of the accessories were furnished by one American manufacturer, except that some of the joints for the later lines were furnished by another American manufacturer.

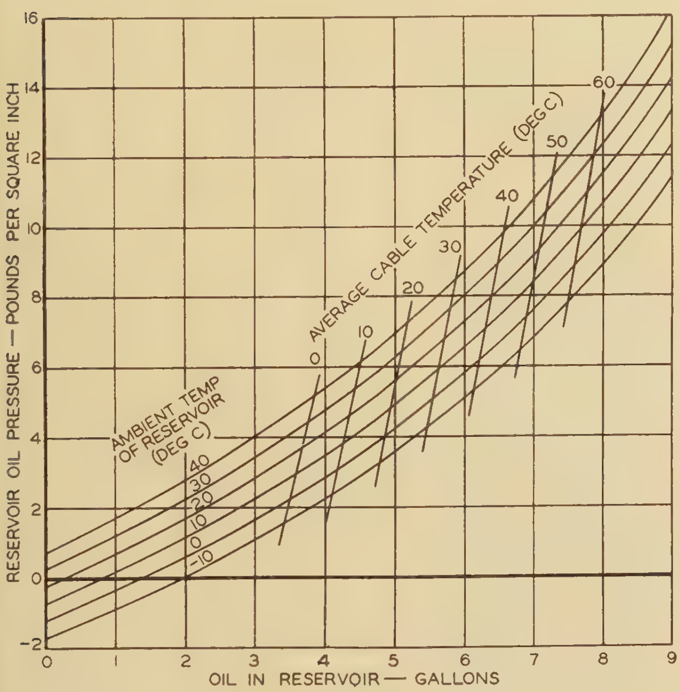



**Figure 6. Operating characteristics of AC reservoirs at one feed point**

At this feed point the oil pressure would be 8 pounds per square inch when the average cable temperature is 40 degrees centigrade and the ambient reservoir temperature is 20 degrees centigrade. At adjacent feed points the pressure on the same phase-section would be higher or lower, in accordance with the intervening hydrostatic head pressure

Normal joints and stop joints, and, in most cases, terminals require application of reinforcement insulation wrappings in the field. In Europe these wrappings usually consist of pretreated paper sheet or tape. In this country bias-cut varnished cloth tape has usually been used because it is easier to apply, is more economical, and there is less chance of absorbing impurities during exposure. In the past a vacuum-treated tape made with black asphaltic varnish has been used. This type of varnish is slightly soluble in oil and increases the power factor of oil exposed to it. While this property is not desirable, it has caused no failures in service.

To overcome this, a new and oil-resistant yellow varnished cloth tape was developed and used for the first time in the Chicago 66-kv accessories. (All accessories were rated at 69 kv.) This new tape also has lower dielectric power factor and is mechanically superior.

One primary requirement was that all joints and reservoirs be sufficiently compact to fit in standard-sized manholes and avoid the inconvenience and expense of manhole enlargement. Normal joints of conventional design easily met this requirement as the internal diameters were 5 or $5^1/_2$ inches and the lengths were 32 to $34^1/_2$ inches. A molded or porcelain sheath insulator was incorporated directly in the copper casing, with a resultant material saving in cost and compactness when compared with separate sheath insulators.

## Stop and Feed Joints

### Herkolite Shell Joint

The ground contour in Chicago is practically flat. It played no part in determining the best location for stop joints with which a line is segregated into sections, except for a few special cases. Other factors, to be described later, determined this. The length of section in Chicago is of the order of 8,000 feet. Because of pressure drop along the cable core and the requirement of keeping maximum allowable pressure within the limits of single lead sheath, it is necessary to have reservoir feed points at intervals of 2,500 to 3,500 feet along the cable. This requires feed joints at these points, intermediate to stop joints, for purposes of connecting the reservoir to the cable core. As this same requirement holds for stop joints also, there is actually no difference in design but only in method of oil

connection. The stop-joint connection definitely shuts off oil flow across the joint while the feed-joint connection allows this flow by means of a controlled by-pass. These joints will be referred to merely as stop joints.

Prior to the 66-kv Chicago installations, the conventional stop-joint design consisted of 2 porcelain shell terminals placed end to end on a horizontal axis, connected electrically together and enclosed in an oil-filled cylindrical copper casing. Each shell assembly is similar in internal construction and appearance to the usual porcelain cable terminal, except that the petticoats are omitted.[2] A stop joint of the porcelain shell design for the 66-kv Chicago installations would be 9 inches in internal diameter and 49 inches in length. This is too large to fit in standard manholes and too costly for frequent intermediate feed points. The development of a smaller and less costly design was an important requirement.

In designs of this type, Herkolite has decided advantages over porcelain. It consists of paper laminations impregnated and cemented together under heat and high pressure. It is only recently that the art of constructing this material in such shapes as required for stop-joint shells has been perfected. It is stronger than porcelain, both mechanically and electrically, and can be molded and machined to exact dimensions. Another advantage is that longitudinal oil-feed channels can be machined on the inner surface of the shell, whereas, with porcelain a clear annular space of much larger dimensions, and with a corresponding reduction in allowable stressing of the oil gap, is necessary.

Changing to Herkolite shells resulted in a material reduction in diameter and length of stop joint. This in turn allowed simpler and more compact methods of compressing the sealing gaskets at each end of the shell. The result has been a stop-joint design retaining the proved ruggedness of the gasketed shell principle but sufficiently compact for standard-sized manholes and little larger than a normal joint.

Figure 4 shows the new Herkolite shell design. The joint dimensions are 5 inches by $40^1/_2$ inches and its internal volume is only 25 per cent of that of the old porcelain design. Its small size allows the incorporation of a sheath insulator in the joint casing, which is another advantage.

When used as a stop joint, it must have one end hydraulically connected to the central casing enclosure for purposes of maintaining oil pressure in this enclosure. If oil feed to the cable in one or both directions is desired with the stop-joint connection, it is necessary to connect separate reservoirs to one or both ends of the joint. When used as an intermediate feed joint, both ends and the central enclosure are connected to a common reservoir.

In the past, the latter connections consisted of short sections of external by-pass piping with necessary fittings and control valves. This method of connection was followed for the joints developed for the first Chicago 66-kv installation. Further study showed, however, a more economical and better mechanical assembly could be realized by incorporating the by-pass connections directly in the joint casing, as illustrated in figure 4. Oil passages connect the end enclosure to the central enclosure at both ends of the joint. The passages can be shut off or left open at will by means of threaded, gasketed plugs, as shown.

### Condenser Joint

The condenser principle of controlling longitudinal and radial stresses in electrical designs is well known. It consists of intermediate electrodes, usually sheets or strips of metal foil, incorporated in the main body of insulation and resulting in a series of small capacities that divide the electrical stress, with a resulting reduction in dimensions. The condenser principle lends itself to stop-joint design, and the details of earlier developments have been described.[3] The condenser unit, representing the main insulation, of the joint, is factory made and materially reduces the field application of insulation wrappings.

The condenser joint designed for the 66-kv system in Chicago meets the main requirement of fitting in standard-sized manholes. It is $5^3/_8$ inches in internal diameter and $42^7/_8$ inches long. This makes it much smaller than previous similar designs. A porcelain sheath insulator is incorporated in the casing by the method of metal-to-porcelain soldering. The oil stop tubes used in the earlier design of joint were eliminated and the oil stop was obtained at the center of the joint by means of an oil-resistant rubber gasket between the connector and the metal tube forming the central inner surface of the condenser unit; the rest of this inner surface is of insulation. Two spring valves in the connector, one on each side of the oil-stop gasket, control the oil passages between the cores of the 2 cable ends and the 2 halves of the joint. The valves are manipulated during joint construction by treated cloth ribbons threaded along the oil-feed space to levers directly under plug openings in the ends of the joint casings; and the ribbons have no function during service as the valves are then open. Passages for by-passing the oil-stop are incorporated in the joint assembly.

The condenser stop-joint design requires more straight cable in the manhole and more care in assembly than the Herkolite shell design, and requires less time for assembly.

## Reservoir Feed System

Considerable time and expense has been given to the possibility of developing new and more economical designs of oil reservoirs. So far, the cell-type reservoir, consisting of a stack of individual cells with corrugated metal diaphragms enclosed in a cylindrical tank, has proved the best. There are 3 modifications of the cell-type reservoir available, all of which are described elsewhere[4] in detail.

The type *CC* gravity-feed reservoir has all cells connected to a common manifold, with the cells filled with oil. The enclosing tank is open to the atmosphere through a breather. It is, consequently, necessary to elevate this reservoir to obtain pressure feed to the cable. On level ground such as exists in Chicago, this involves expensive feed towers.[1] In the present 66-kv Chicago system, type *CC* reservoirs are used only at the vertical terminal ends where the desired elevation is already available on the switching structure.

The type *DC* balanced-pressure reservoir is similar to the type *CC* except that the enclosing tank has extra length and is sealed full of gas. The gas pressure may be adjusted as desired, and so it is not necessary to elevate this type of reservoir. Rather exact control of the oil feed can be obtained even with reservoirs at different elevations.[5,6] In making the type *DC* reservoir, there is a great deal of brazing and other hand work in paralleling the cells to the manifold, which increases cost.

The type *AC* reservoir has a simpler and more economical cell arrangement. The cells are individually sealed off full of air at atmospheric pressure by automatic welding. Elimination of manifold connections materially reduces hand work and cost. The oil is in the enclosing tank instead of the cells. The pressure on the oil is obtained by forcing in enough oil to compress the air cells, and for this reason is not under complete control. Unlike the type *DC* reservoir, a relatively high oil pressure cannot be obtained when the reservoir is nearly empty, or a relatively low pressure when the reservoir is nearly full. The maximum safe operating pressure is about the same as the limit dictated by the strength of the sheath, i.e., 15 pounds per square inch.

**Table I. Economics of 2,100,000-Circular-Mil 66-Kv Lines in Fall of 1935**

Figures Include Indirect Costs

| | Type of Insulation | |
|---|---|---|
| | Oil Filled | Ordinary |
| **Costs per Mile of Line** | | |
| INVESTMENT: | | |
| Cable | $ 55,900 | $ 71,800 |
| Accessories | 15,740 | 6,010 |
| Installation | 12,800 | 9,580 |
| Conduit, prorated | 21,870 | 21,000 |
| | $106,310 | $108,390 |
| ANNUAL CHARGES: | | |
| Fixed: Cable at 11½ per cent | $ 9,700 | $ 10,040 |
| Fixed: Conduit at 10½ per cent | 2,300 | 2,210 |
| Copper losses | 1,550 | 1,490 |
| Dielectric losses | 320 | 250 |
| Maintenance | 440 | 330 |
| | $ 14,310 | $ 14,320 |
| **Emergency Carrying Capacity, Kilovolt-Amperes** | | |
| Summer | 115,000 | 105,000 |
| Winter | 135,000 | 115,000 |
| **Annual Charges per Kilovolt-Ampere of Carrying Capacity** | | |
| Summer: cents | 12.4 | 13.6 |
| Summer: per cent | (100) | (109) |
| Winter: cents | 10.6 | 12.5 |
| Winter: per cent | (100) | (118) |

In spite of its simplicity, the type *AC* reservoir is not so economical as the type *DC* on hilly contour because the hydrostatic head pressure on the reservoirs at low elevations causes them to become partly filled with oil, thus wasting much of the capacity. With type *DC* reservoirs, it is only necessary to pump up the gas pressure to avoid this.

On reasonably level contour, as in Chicago, a material saving may be realized by using type *AC* reservoirs, even though the efficiency is rather low. The ratio of useful to total capacity of the *AC* reservoirs in Chicago is 50 per cent.

This means that about twice as much manhole space is required for the *AC* reservoirs as for corresponding *DC* reservoirs. In the past it has been customary to install *DC* reservoirs for all 3 phases of single-conductor cable in the same manhole. There is not room to do this with *AC* reservoirs without having a great number of feed points, and so a staggered feed system has been adopted. The reservoirs and the feeder joint for one phase are installed in a given manhole with those for the other 2 phases in usually the next manhole on each side. This method gives ample space with standard-sized manholes and results in economy in the use of feeder joints. Figure 5 illustrates diagrammatically some typical arrangements of stop joints, intermediate feeder joints, and reservoirs for various lengths of line sections used in Chicago.

From 2 to 4 9-gallon type *AC* reservoir units were connected in parallel at each feed point, depending upon the ground contour and the length of cable to be fed. In each section the total useful reservoir capacity was calculated to take care of the thermal expansion of the oil in the cable and accessories over the full annual temperature range, and without exceeding an allowable pressure range for the cable and reservoirs. Thirty per cent or more surplus reservoir capacity was added to the cable oil requirement for emergency use. The pressure limits were 0.5 pound per square inch above atmospheric pressure at the highest point of the section with all surplus exhausted and 17 pounds at the lowest point in the cable at maximum load temperature. In addition, it was necessary to make sure that the available reservoir pressure was sufficient to take care of maximum pressure drop in oil piping connections and along the cable core under all conditions of oil demand by the cable and accessories,[7] due both to temperature changes and exchange of oil between reservoirs caused by the semibalanced system of feed adopted.

Semibalanced pressure feed of the type just described makes the calculation of reservoir settings as a function of cable temperature more difficult and complicated than balanced pressure feed. The general mathematical formulas involved have been published,[6] but yet it is necessary also to resort to a cut-and-try method.

As previously explained, the reservoir oil pressure is practically equal to the gas pressure in the cells. This means that the ambient temperature of the reservoir affects the pressure. The complete pressure-volume-temperature characteristic of the 9-gallon *AC* reservoir is shown in figure 6 (curves slanting upward to right). Using this characteristic, oil pressures and corresponding oil volumes satisfying the following conditions are determined (by cut-and-try):

1. The total volume of oil in all the reservoirs on a phase of a line section at a given cable temperature must be in accordance with the calculated thermal expansion of the cable and accessories at that temperature.
2. The corresponding pressures in each group of reservoirs must lie within the allowable range, and the differences in pressure between reservoir groups must be equal to the hydrostatic pressures due to the differences in elevation.

After a sufficient number of such points has been determined, they are plotted on the reservoir characteristic, and points for equal cable temperature are connected by the vertical cross-lines shown in figure 6. One of these graphs is prepared for each feed point along the line. With the help of these, it is easy to determine the correct reservoir pressure for all stable conditions of cable and reservoir temperature. A short circuit heat run on the first Crawford-Humboldt line showed the calculated reservoir pressures to agree closely with the actual.

## Oil Relay Protection

Oil-filled cable furnishes an opportunity that usually does not exist with solid-type cable to detect leaks in the system, by means of oil relays, before electrical service failures develop from entrance of impurities. Such leaks as slight defects in the sheath, pipe fittings, or lead wipes, may be slow and require weeks to exhaust the reservoirs. Practically all of the leaks that have developed in previous oil-filled lines have been of this type. As long as the reservoirs are not exhausted, positive pressure is maintained and leakage of oil outward prevents entrance of impurities. Fast leaks may be caused by electrical failure or direct mechanical rupture of oil piping. Such fast leaks may exhaust the reservoirs in from 1 to 4 hours, depending upon restrictions offered and oil viscosity, and require a well-organized emergency repair system to prevent such exhaustion.

Regardless of the type of leak that develops, it is obviously desirable that the station operator learn of it as soon as possible. Relays set for minimum oil reservoir volume or pressure are necessarily slow in action, the reservoirs being fairly well exhausted before an alarm comes into the station. With 3-conductor cable, minimum setting relays are the only type that are economically acceptable. For gravity feed with single-conductor cable, differential-volume relays are fast and satisfactory. For single-conductor cable with balanced or semibalanced pressure reservoir feed, fast relay action is obtained by utilizing differential oil pressure between phases.

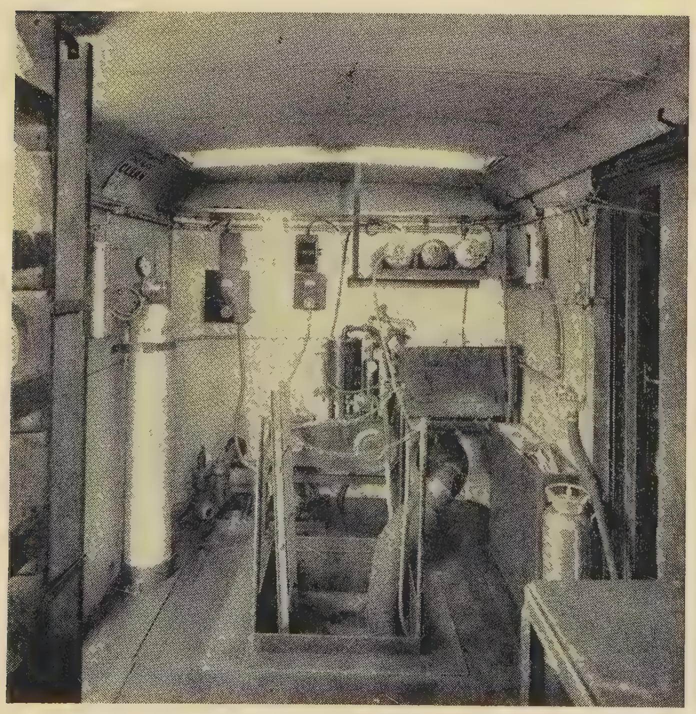


Figure 8. Trailer over manhole during jointing

Under normal balanced load conditions, the oil pressure in the different phases varies in the same way at any given point in a section. In case of oil leakage, the pressure decreases in the faulty section. The possibility of pressure in all 3 phases decreasing at exactly the same rate due to leakage is so remote that differential pressure between phases furnishes a reliable way of obtaining fast oil-relay action. It was necessary, however, to devise a phase differential relay that would do 2 things. First, means had to be found for compensating for differences in hydrostatic head pressure between different phases or at different points in any one section, caused by differences in elevation. Second, the reservoir pressure normally varies over a relatively wide range from no load in winter to full load in summer, which in extreme cases might be from one pound to 15 pounds. A differential setting of a small fraction of one pound would be necessary to properly take care of no load conditions, but this same setting would be too sensitive and lead to false alarms under full load conditions. What was desired was a differential relay having an operating differential pressure that would increase proportionately with the line oil pressure.

Both of these things are accomplished in the design shown diagrammatically in figure 7, first used in the 66-kv Chicago system. The relay consists essentially of 2 small opposing sylphon bellows having predetermined differences of area (the smaller has 25 per cent less area than the larger). Each opposing bellows is connected by oil piping to cable or reservoirs in different phases. At any point in the working pressure range the oil pressure in the large bellows must drop 25 per cent below the oil pressure in the small bellows to actuate the mercury switch shown. This switch is connected through relay wiring to any desired type of alarm system at the station. By connecting 3 pairs of opposing bellows as shown in figure 7, not only will the relay operate if the pressure in any phase drops 25 per cent below that in the other 2 phases, but it will also operate if there is a 33 per cent increase in any phase, the operation in this latter case being reversed.

Since the compensating spring across each of the large bellows may be adjusted to compensate for and nullify hydrostatic head pressure, the relay is actuated entirely by variable working pressure, or rather by a constant percentage differential pressure within this working range.

## Bonding of Sheaths

With such large lines, the ratio of sheath losses to copper losses in case the sheaths are solidly bonded together would be about 225 per cent. Since experience showed that satisfactory insulating sleeves and methods of bonding had been developed to eliminate sheath losses, they were used.

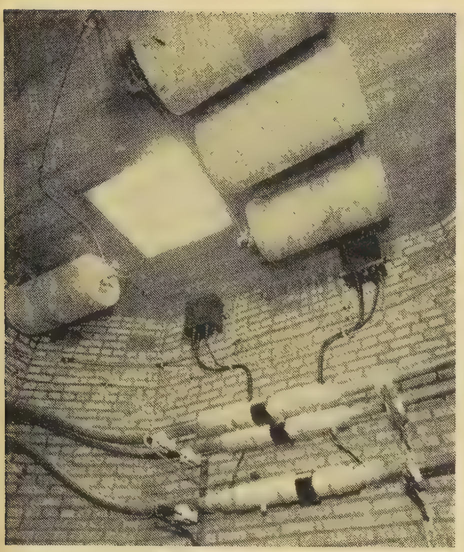


Figure 9. Accessories installed in manhole

Lower center—Two normal joints in upper position and Herkolite shell-type feeder joint in lower position. Note sheath insulators in joint casings and porcelain insulators under cables

Top—Four type AC 9-gallon reservoirs connected to feeder joint; reservoirs are placed with valves accessible from manhole opening

Upper center—Two bonding transformers, one connected on each side of sheath insulators in joint casings

Note: Cable and joints are fireproofed before line goes in service

Operating experience in Chicago indicated that for normal maximum loads of about 95,000 kva, the maximum allowable induced sheath voltage to ground from the standpoint of avoiding a-c electrolytic corrosion was about 11 volts. For emergency loading, the corresponding potential is about 15 volts. If the ordinary schemes of bonding were used, such as cross-bonding, then the maximum allowable length of cable between insulating sleeves would be about 320 feet based on normal loading, and somewhat less if based on emergency winter loads. The use of sheath bonding transformers[8] to reduce the voltage to ground to about 50 per cent of the induced voltage between insulating sleeves made it possible to use conduit sections up to 615 feet. During emergencies, the induced voltage from sheath to ground is about 16 volts, but the flow of exciting current through the sheath and bonding transformers reduces this potential to 15 volts with negligible sheath losses.

Cable lengths of the order of 615 feet are satisfactory also from the standpoint of allowable cable movement because during normal loading the daily cable movement at a duct mouth would be 0.4 to 0.55 inch and during emergencies the movement would be 1 to $1^1/_4$ inches. Chicago experience indicates that movements 40 or 50 per cent larger would be safe from the standpoint of obtaining long life of the sheath in the manhole without cracking.

The 3 phases of the lines had to be transposed frequently in order to minimize the induction of voltages and currents in other cables in the same conduits. The piping from the reservoirs was connected to the joints through pipe insulators. On end laterals, the practice was to ground the potheads and to have an insulating sleeve in the first joint.

## Installation

Theory and experience have indicated that special care must be exercised, not only in the factory but also during installation and operation, to avoid the ingress of impurities in oil-filled cable. In view of this situation, and the need for considerable engineering work on development of suitable accessories and on the reservoir layout system, it was found desirable to have more engineers employed in connection with the new lines than would have been the case with cable of the ordinary type. Such engineers also follow the work continuously during installation and are of considerable assistance to the field force.

The installation of the various types of joints requires in each case more than the usual working day of 8 hours. As a matter of efficiency in the use of equipment and man power, a new method of underground work was developed, that is, to construct in series all 3 joints and related work in a manhole on a continuous basis. In the 1937 work, 2 field crews each comprising 3 gangs and substitutes worked continuously 7 days a week, night and day, doing manhole work. By this means, the overtime payroll is kept down to a negligible amount and the efficiency of supervisors and splicers is not impaired by long working hours. Another advantage is that practically all the work in a manhole is completed in *one* set-up with a substantial saving in transportation and labor costs.

A further improvement adopted is the use of 2 specially built trailers. The trailer is set over a manhole opening, access to which is provided by means of an opening in the floor. This arrangement provides increased protection for the men against inclement weather and traffic hazards, in addition to keeping moisture and dirt from entering the manhole. See figure 8. Gasoline-engine-driven generators were used for power supply for equipment such as oil heater, water pump, air blower, and vacuum pump. Excellent lighting, which is conducive to good workmanship and a minimum of fatigue, was also provided thereby.

The following items briefly outline checks or procedures in the field to carry out the principle of preventing the ingress of impurities in the lines:

1. A final expulsion test and pressure check are made on each reel of cable immediately before installation.

2. The oil pressure in temporary reservoirs is frequently checked to make sure that the cable is under positive pressure and adequate oil supply is available for the flushing during jointing.

3. Care is taken during the installation to maintain the cable oil pressure *above* atmospheric pressure at all times. Only 2 short-time exceptions to this rule are permissible, namely:

(*a*) At the end of the time of installing the cable in the duct, when the source of oil feed to the cable is transferred from the reel reservoir to the temporary reservoir in the manhole.

(*b*) On soldering the connectors onto the conductors.

4. Vacuum tests are made on each completed joint prior to final filling with degasified oil.

5. The application of vacuum is always localized, i.e., the principle of not subjecting a cable length to vacuum in the field is followed.

6. Flow checks are made shortly after completion of each line section in order to determine the presence, if any, of partial or complete restrictions to oil flow in the joints or in the connecting piping.

7. Impregnation checks are made shortly after completion of joint work on each section, as an over-all check on the presence of air.

Tests and procedures used in the field designed to prevent the use of contaminated or overheated oil are as follows:

1. All degasified oil used in constructing the joints, filling the temporary oil reservoirs, and for additions to the permanent reservoirs is treated in Chicago. Such oil is the same as that furnished in cable and in reservoirs. Each lot of treated oil is required to meet the following requirements:

| Item | Temperature | Limiting Values Maximum | Limiting Values Minimum |
|---|---|---|---|
| Power factor—per cent | 100 deg C | 0.50 | |
| Resistivity—ohms per cm³ | 100 deg C | | $15 \times 10^{12}$ |
| Gas content—per cent | Room | 1.0* | |
| Dielectric strength | Room | | 25 kv 1 min. |
| Color number | | 1 1/2 minus | |
| Organic acidity—mg KOH/g | | 0.020 | |

* Reduce to 0 degrees centigrade and 76 centimeters mercury.

2. The maximum temperature to which the oil is subjected in the degasifying plant is 100 degrees centigrade.

3. After each soldering operation during installation of joint connectors, oil is drained from the cable to remove overheated oil and residual flux.

4. Dried oil used for flushing purposes during the construction of joints is heated by indirect means to 110–125 degrees centigrade. The supply of heated oil is changed daily and the tank is cleaned frequently.

5. The principle of not soldering accessories or piping containing oil that could thereby be overheated is followed.

6. Hot flushing oil is admitted to the joint casings after wiping and before proceeding with the vacuum and filling treatment.

7. All piping is swabbed, flushed, and temporarily sealed preparatory to installation. Wherever possible, the piping is vacuum treated and filled with oil at the time the joints are treated. When this cannot be done, the tubing is treated and filled separately and then joined to the filled joint with oil flowing out of the fittings to preclude entrance of air or moisture.

A view of completed construction work, excepting fire-proofing, in a manhole is shown in figure 9.

Before the installation of the 1936 line was considered completed, a thorough load test at reduced voltage was made. One purpose of the load test was to heat the line and distribute any traces of moisture that might have entered the joints or oil system. Records of load currents, conductor temperatures, oil volumes and pressures in reservoirs, induced sheath voltages, cable movement, and performance of oil-pressure signal system equipment were obtained. The results were satisfactory, inasmuch as the performance under load agreed closely with the calculations on which the line design was based.

When the load test was made on the 1936 line, other future lines of the same type were under consideration and it was felt desirable to check thoroughly the many new developments incorporated in the line. Such was not considered necessary for the 1937 installations. In general it appears probable that, for future oil-filled lines, special heat runs will be unnecessary.

The installation tests of 140 or 150 kv direct current for 15 minutes were made with the permanently installed kenotrons of the utility.

## References


1. Symposium, 132-Kv, Single-Conductor, Lead-Covered Cable, P. Torchio, L. Emanueli, W. S. Clark, A. H. Kehoe, C. H. Shaw, J. B. Noe, and D. W. Roper. AIEE Transactions, volume 47, January 1928, pages 186–210.

2. The 220 Kv System of the Paris Area, Josse and Laborde. *Revue Generale de l'Electricite*, 1936, pages 827–45, 863–76.

3. Oil-Filled Cable and Accessories, R. W. Atkinson and D. M. Simmons. AIEE Transactions, volume 50, December 1931, pages 1421–29.

4. Oil Pressure Reservoirs for Underground Cable, T. C. Aitchison. *General Electric Review*, July 1931.

5. Characteristics of Oil Filled Cable, G. B. Shanklin and F. H. Buller. AIEE Transactions, volume 50, December 1931, pages 1411–20.

6. Theory of Oil-Filled Cable, G. B. Shanklin and F. H. Buller. *General Electric Review*, July 1931.

7. Thermal Transients and Oil Demands in Cables, K. W. Miller and F. O. Wollaston. AIEE Transactions, volume 52, March 1933, pages 98–110.

8. Reduction of Sheath Losses in Single-Conductor Cable, Herman Halperin and K. W. Miller. AIEE Transactions, volume 48, April 1929, pages 399–414.


## Italian State Railway Acquires New Electric Trains

The first of several new electric trains, being constructed by Società Breda for the Italian State Railway system, recently was placed in service. Said to be capable of attaining a maximum speed of 180 kilometers (about 112 miles) per hour, the train consists of 3 intercommunicating cars resting on 4 2-axle carriages, is 62.5 meters long, has a maximum breadth of 2.92 meters, and weighs 100 tons. The motive power is supplied by 6 3,000-volt series-wound d-c motors with a total rating of 1,200 horsepower. Two motors are mounted on each of the end carriages, and each of the middle carriages carries one motor. Air braking is used. Each of the 3 cars is air conditioned; the middle car contains a single first-class saloon with 35 seats, and the end cars contain second-class compartments with seating accommodations for 59 passengers. The kitchens are in one end car, and the baggage and mail compartments in the other.

# Insulation Strength of Transformers

## Purpose

THIS PAPER is presented to review the work of the transformer subcommittee in setting up standards for the insulation strength of transformers. An effort will be made to present the steps in the development of the insulation co-ordination problem in regard to transformers and to clarify certain points on which misunderstandings have arisen. The present insulation strength standards and tests will be given so that the margin between the protective level and insulation strength as demonstrated by test may be given proper consideration.

As the transformer subcommittee has before it a proposal for changes in standards necessary for the use of kilovolts as the basis for impluse tests instead of the use of the spacing of the test (rod) gaps, these proposals will also be given.

## General

Transformers have an impulse insulation strength as actually demonstrated by the standard insulation tests, and an ultimate breakdown strength somewhat higher. The margin between the demonstrated strength and the ultimate breakdown strength represents the safety factor which is provided by the designer. Logically, only the strength as demonstrated by test should be used in the application and co-ordination of transformers. In the operation of the transformers, a reasonable margin between the tested strength of the transformer and the protective level should be established and maintained as an additional safety factor in view of unpredictable conditions.

The insulation strength of transformers may be considered from 2 points: the 60-cycle strength and the impulse strength. The 60-cycle strength determines the ability of a transformer to withstand continuous 60-cycle voltages, most switching surges, and arcing ground overvoltages. The impulse strength is that strength which resists lightning overvoltages and the higher switching surges. Initially the insulation was determined by 60-cycle tests as a measure of ability to withstand all normal service requirements but as experience was gained more attention was given to the impulse strength. The present 60-cycle insulation test level has been in existence for some time and appears to have been adequate.

Before the present knowledge with regard to lightning and transformer insulation properties was obtained experience was the only guide. In the development of transformer insulation to withstand lightning overvoltages, changes in design were made where experience indicated it was necessary. Accordingly, when sufficient knowledge of lightning overvoltages and transformer insulation properties were obtained insulation levels and the corresponding insulation tests could be intelligently set up. The 60-cycle test has been retained and an impulse test has been added as a means of demonstrating impulse strength of the transformer.

A report of the transformer subcommittee of the AIEE committee on electrical machinery compiled by J. E. Clem and A. C. Monteith; recommended for publication by the AIEE committees on power transmission and distribution, protective devices, and electrical machinery. Manuscript submitted March 20, 1937; released for publication April 24, 1937.

Personnel of transformer subcommittee of AIEE committee on electrical machinery: I. W. Gross, *chairman;* J. E. Clem, *secretary;* E. S. Bundy, L. H. Hill, V. M. Montsinger, A. C. Monteith, J. R. North, M. S. Oldacre, H. B. Scholz, and F. J. Vogel.

## Historical

The standards for insulation tests have had a varied history. The first insulation standards were adopted June 26, 1899, and were as follows, as applicable to transformers:

**38.** The following voltages are recommended for apparatus not including transmission lines or switchboards

| Rated Terminal Voltage | Capacity, Kilowatts | Testing Voltage |
|---|---|---|
| Not exceeding 400 | Under 10 | 1,000 |
| Not exceeding 400 | 10 and over | 1,500 |
| 400 and over, but less than 800 | Under 10 | 1,500 |
| 400 and over, but less than 800 | 10 and over | 2,000 |
| 800 and over, but less than 1,200 | Any | 3,500 |
| 1,200 and over, but less than 2,500 | Any | 5,000 |
| 2,500 and over | Any | (Double the normal rated voltages) |

Modifications were made from time to time during the intervening years until the present insulation standards for the low frequency tests were issued May 1930. These are essentially as given below:

### Dielectric Test

**13–400 Standard Test Voltage to Be Applied Between Windings and Between Windings and Ground.** Transformers and other induction apparatus, except as listed below, shall be tested by applying between each winding successively and ground an alternating voltage from an external source of twice the rated voltage of the circuit to which the winding under test is to be connected plus 1,000 volts. All other electric circuits and metal parts shall be grounded during this test.

**13–401 Standard Test Voltage Between Turns to Be Induced in the Windings.** Transformers and other induction apparatus, except as listed below, shall, in addition to the tests provided in 13–400, be tested by applying between the terminals of one winding a voltage of twice the normal voltage developed in that winding, corresponding voltages being induced in the free windings.

### Exceptions:

(*n*) Transformers with graded insulation: Transformers, if for use on circuits of 66,000 volts and above, and having windings directly and permanently grounded and designed to take advantage of the fact that the neutral or other point of the circuit is to be directly and permanently grounded,* shall be tested by induced voltage with connections so made that the ungrounded or line

* A circuit shall be considered directly grounded when transformer connections and characteristics are such that not less than twice the combined rated line currents from the bank or banks of transformers supplying the circuit will flow to ground when a line is grounded at a terminal of any of the transformers supplying the circuit.

## Table I. Progress of Requirements for Impulse Strength* of Transformers

| Limit of Rated Trans. Voltage (Kv) | November 1930 | | December 1932 | | January 1933 | | December 1934 | | January 1937 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Line Insulators | Impulse Flashover (Kv) | Co-ordination Gap Spacing (Inches) | Impulse Flashover (Kv) | Test Gap Spacing (Inches) | Impulse Flashover (Kv) | Test Gap Spacing (Inches) | Impulse Flashover (Kv) | Test Gap Spacing (Inches) | Impulse Flashover (Kv) |
| 1.2 | | | | | | | 0.8 | 32 | 0.8 | 32 |
| 2.5 | | | | | | | | | 1.6 | 53 |
| 5.0 | | | | | 2.25 | 63 | 2.2 | 63 | 2.2 | 63 |
| 8.7 | | | | | 3.375 | 81 | 3.3 | 80 | 3.3 | 80 |
| 15.0 | | | 4.25 | 95 | 4.75 | 102 | 4.5 | 100 | 4.5 | 100 |
| 25.0 | | | 6.25 | 128 | 7.00 | 141 | 6.9 | 140 | 7.1 | 150 |
| 34.5 | | | 9.25 | 180 | 10.25 | 190 | 10.2 | 190 | 10.2 | 190 |
| 46.0 | | | 12.25 | 228 | 13.5 | 250 | 13.5 | 250 | 13.5 | 250 |
| 69.0 | 4 | 440 | 18.75 | 335 | 20.5 | 360 | 20.6 | 360 | 20.6 | 360 |
| 92.0 | 6 | 610 | 25.0 | 430 | 27.5 | 470 | 27.5 | 470 | 27.5 | 470 |
| 115.0 | 7 | 695 | 31.5 | 525 | 34.75 | 570 | 34.7 | 570 | 34.7 | 570 |
| 138.0 | 8 | 780 | 38.25 | 625 | 42.0 | 680 | 42.1 | 680 | 42.1 | 680 |
| 161.0 | 10 | 945 | 44.5 | 720 | 49.0 | 790 | 49.0 | 790 | 49.0 | 790 |
| 196.0 | 12 | 1,105 | 54.5 | 860 | 60.0 | 950 | 60.0 | 950 | 60.0 | 950 |
| 230.0 | 14 | 1,265 | 64.0 | 1,000 | 70.5 | 1,100 | 70.4 | 1,100 | 70.4 | 1,100 |
| 287.5 | | | | | | | 88.0 | 1,360 | 88.0 | 1,360 |
| 345.0 | | | | | | | 105.6 | 1,620 | 105.6 | 1,620 |

* Flashover voltages lifted in table are present day values and are crest of $1^1/_2 \times 40$ microsecond impulse wave with flashover on wave tail (minimum wave to produce flashover of square cut rod gap).

terminals shall receive test voltage to ground not less than 2.73 times the normal voltage developed by the winding, plus 1,000 volts.

If testing circuit conditions are such that the induced voltage test just specified does not at the same time produce between adjacent 3-phase line terminals twice the related voltage of the circuit, additional test with the same or other circuit connections shall be made to produce this voltage between line terminals; i.e., twice the rated circuit voltage.

Transformers having graded insulation shall be so marked.

Some time prior to the 1930 revision it was realized that it was necessary to supplement the low-frequency test with an additional test to insure that transformers were insulated more in proportion to the overvoltages to which they might be subjected. In some cases line insulation was increased to reduce lightning outages. It was becoming more and more recognized that the most important source of the damaging overvoltages was lightning and that some effort should be made to correlate the insulation strength with the lightning overvoltages. Considerable discussion on this problem took place in the transformer subcommittee and a series of reports have been issued from time to time, the essential features of which are given in table I and discussed in the following paragraphs.

In November 1930[31] the first report was issued in which it was required that

Apparatus conforming with the standards of dielectric test should be so designed that their impulse strength against lightning is greater than the impulse flashover voltage to earth of nonshielded suspension type insulators. . . .

and it was also proposed that no line entering the station have insulation exceeding these values for half a mile from the station.

The manufacturers tried to design to these levels but in as much as there was no established testing procedure, it is not possible to know whether they were successful.

This was the first effort at what for a long time has been called "co-ordination of transformer insulation." The use of insulators as the basis of comparison did not last very long for many reasons, the most important being the obvious disadvantage of the large and inflexible steps and the fact that the proposed reduction of the last half mile of line insulation to these values was not generally adopted.

31. For all numbered references see list at end of paper.

In December 1932[21] a revision was published in which the impulse strength against lightning was given in terms of the spacing of a rod (co-ordination) gap of specified construction and the tabulation was extended to include the 15-kv circuit.

The previous proposal of November 1930 balanced the transformer insulation strengths against a specified number of line insulators in half a mile of line adjacent to the station while the revision of December 1932 balanced it against the "co-ordination gap." It was thought if one flashover point was established where the lines entered the station instead of 3 or 4 spaced one half a mile out that the single gap should be about 10 per cent less in flashover value to establish the same level on account of attenuation. Consequently, the spacing of co-ordination gap was selected to give about 10 per cent less flashover than the line insulators. However, in comparing the impulse flashover values in table I it should be remembered that the numerical values on which the comparison was made then was not the same as those used today.

The transformer subcommittee continued its studies and in January 1933 presented[16] a tentative test code. In this test code the use of the term "co-ordination gap" was definitely abandoned as a means of expressing transformer insulation strength. The use of test gaps at 110 per cent of the co-ordination gap spacing was introduced, the tabulation was extended to include the 4,600-volt class, a standard test wave was established, and a schedule of 5 tests adopted. These tests are as follows:

### Tests to Be Applied

Each terminal of the transformer to be tested should be tested with waves of positive polarity having respectively:

1. A voltage not more than 10 per cent less than the minimum impulse voltage permitted by the specified test gap directly connected to ground.

2. A voltage just sufficient to flashover the specified test gap directly connected to ground.

3. A crest voltage at least 10 per cent greater than the minimum flashover voltage of the test gap directly connected to ground.

4. A voltage of sufficient magnitude to flashover the bushing.

5. A voltage as great as that specified in number 3 or 4, but with the means for maintaining the excitation voltage across all parts of the winding.

In December 1934[9] the number of impulse tests was reduced from 5 to 3 and the tabulation was extended up to 345 kv and down to 1.2 kv. A slight modification of the impulse test gap spacings, and a change in the low-frequency test voltage for transformer ratings 23 kv and below were also reported.

At this time a standard bushing level was considered. The values adopted were 15 per cent above the co-ordinating gap for distribution transformers. The power transformer bushings 69 kv and above followed the values, but on account of past practice with power transformers in the lower voltage classes, it was felt that the bushing should have a higher level and values essentially those of table III were adopted.

In January 1937[2] some slight changes were reported. These changes consisted in the correlation of circuit voltages with corresponding maximum apparatus voltage ratings and the conclusion of the low-frequency test voltage in the tabulation. The wording of the 3 impulse tests were changed slightly to read as follows:

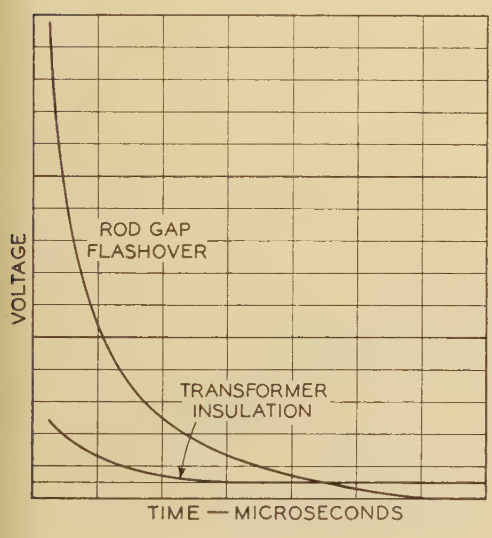



**Figure 1. Typical volt-time characteristics of rod gap and transformer insulation**

### Impulse Tests

(*a*) Apply a wave just sufficient to cause flashover of the specified test gap under existing conditions of humidity and air density.

(*b*) Apply a wave sufficient to cause flashover of the bushing. For this test the applied voltage must be at least 5 per cent in excess of the standard minimum flashover voltage for the standard bushing under standard conditions of humidity and air density.

*Note*—When oversized bushings are used they shall be equipped with suitable gaps to provide the same standard minimum impulse flashover as for the standard bushing.

(*c*) Apply a wave having a crest not less than 90 per cent of the standard minimum flashover voltage of the standard bushing under existing conditions of humidity and air density. No flashover of the bushing shall occur during the test.

## Comments

### Insulation Strength "Yardstick"

It has frequently been asked why insulators and rod gaps were initially used as a means of expressing insulation levels. The reason is as follows: Impulse testing was a new development and the technique had not been established. The impulse flashover of a given number of insulator units or of a given gap spacing was reported differently by different laboratories. It was felt that the actual voltage required to flashover a specified rod gap or a specified number of insulators would be the same in all the laboratories regardless of the variation in reported values. Consequently it was felt that if the impulse strength level of a transformer was specified in terms of the impulse flashover of a given number of line insulators or a given gap spacing, it would result in a common "yardstick" for expressing the insulation strength of transformers.

### Polarity of Test Wave

Many have asked why the positive polarity wave was selected instead of a negative polarity wave. These questions were prompted by the fact that it was later definitely established that the severest lightning overvoltages on transmission lines were of negative polarity. At the time the positive wave was selected, which actually was some time prior to the issuance of the proposed impulse test code, it was not generally accepted that the negative waves were predominant in the lightning overvoltages on transmission lines. The reason for the adoption of a positive polarity is the fact that the problem of impulse testing was in the development stage at the time, and laboratory technique was being built up with the use of positive polarity. As a result, by far the greater amount of impulse data had been obtained with positive waves and it was felt that co-ordination could be accomplished to better advantage if the positive wave was selected for transformer testing.

### Co-ordination Gap as Protective Device

When the problem of co-ordination was first considered the reduced line insulation as proposed in November 1930 or the "co-ordination gap" as proposed in December 1932 was presumed to offer adequate protection to transformers. The expression "co-ordination gap" signified not only a particular type of gap, but also a particular spacing for each voltage. This idea that the "co-ordination gap" was an adequate protective device has persisted in spite of the increased knowledge of the divergence of volt-time characteristics of rod gaps and transformer insulation.

The volt-time characteristic of rod gaps and transformer insulation may be the same in general, but they are decidedly different in detail. As the time to flashover becomes shorter the flashover voltage of the gap increases considerably faster than the breakdown voltage of the transformer insulation. This is illustrated in figure 1, and it is very evident from the curves that the "co-ordination gap" offers no protection when the time to gap flashover is short and when protection will most likely be needed. In order to establish the same margin of protection at half a micro-

second, it would be necessary to reduce the gap spacing to about $^1/_2$ to $^1/_3$ of the co-ordination gap; If this was done the number of service interruptions would very likely be increased.

In general it may be said that plain air gaps or rod gaps will limit by flashover the magnitude of the stress applied to station apparatus but their volt-time characteristics are so different from transformer insulation that they may be considered as affording a definitely limited amount of protection. The economics of the situation and the grade of service acceptable are the governing factors.

### Standard Insulation Levels for Transformers

The transformer subcommittee at its meeting January 27, 1937, authorized the change from gap spacing to kilovolts as the measure of transformer insulation strength. A new tabulation is presented in table II which converts the present test code values from inches to kilovolts, and omits the minimum flashover voltage of the gap. There is given, also, the low-frequency test voltage values. The kilovolt values are practically identical with those required by the present test code through the requirement of bushing flashover, although the testing procedure has been altered. A discussion of the impulse test values in the light of the present test recommendations and basic insulation levels adopted by the EEI-NEMA joint committee on insulation co-ordination may be helpful.

The present impulse test code provides for application of 3 1.5x40 positive test waves to transformers, with specified tolerances, one a full wave at 90 per cent of the flashover voltage of the proposed standard bushing, one a wave chopped late on the tail by the test gap, and one a wave chopped early on the tail by bushing flashover with an applied voltage of 105 per cent of the standard flashover voltage of the bushing. Expressed in per cent these are:

| | | |
|---|---|---|
| Applied voltage—test gap flashover | = | 100 per cent |
| Applied voltage—bushing flashover | = | 110 per cent |
| Applied voltage—full wave test | = | 95 per cent |

except for power transformers rated 69 kv and below where the bushings have an impulse flashover higher than on distribution transformers which results in correspondingly higher impulse test voltages being applied to power transformers. This higher impulse strength of power transformers in the 69 kv class and below is inherent in these transformers and is required by the present test code which bases maximum impulse tests on the flashover of the transformer bushing.

It should be noted that the basic insulation levels adopted January 1937 by the EEI-NEMA joint insulation committee on system insulation correspond to the test gap flashover (minimum impulse flashover—full wave) of 100 per cent given above. The test gap flashover voltages are listed in table I in the January 1937 columns. Therefore in order to insure that when the tests are expressed in kilovolts they shall be of the same severity as when formerly ex-

**Table II. Standard Insulation Test Level—Distribution and Power Transformers**

| | | Standard Insulation Test Level | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Impulse Test—1.5x40 Microsecond Wave | | | | | | |
| | | Distribution Transformers | | | Power Transformers | | | |
| | | Full Wave | Chopped Wave | | Full Wave | Chopped Wave | | |
| Rated Circuit Voltage (1) (Volts*) | Limit of Rated Trans. Voltage (2) (Kilovolts**) | Voltage (3) (Kilovolts) | Voltage (4) (Kilovolts) | Min. Time to Flashover (5) (Microseconds) | Voltage (6) (Kilovolts) | Voltage (7) (Kilovolts) | Min. Time to Flashover (8) (Microseconds) | Low Frequency Test Voltage (9) (Kilovolts) |
| 120, 240, 480, 600 | 1.2 | 30 | 36 | 1.0 | 60 | 69 | 1.5 | 10 |
| 2,400, 2,500 | 2.5 | 50 | 59 | 1.25 | | | | 15 |
| 4,160, 4,330, 4,800 | 5.0 | 60 | 69 | 1.5 | 76 | 88 | 1.6 | 19 |
| 6,900 | 8.66 | 76 | 88 | 1.6 | 95 | 110 | 1.8 | 26 |
| 11,500, 13,800 | 15.0 | 100 | 115 | 1.8 | 112 | 130 | 2.0 | 34 |
| 25,000 | 25.0 | 140 | 165 | 2.5 | 153 | 180 | 3.0 | 51 |
| 34,500 | 34.5 | 185 | 210 | 3.0 | 195 | 225 | 3.0 | 70 |
| 46,000 | 46.0 | 240 | 275 | 3.0 | 245 | 290 | 3.0 | 93 |
| 69,000 | 69.0 | 340 | 395 | 3.0 | 345 | 405 | 3.0 | 139 |
| 92,000 | 92.0 | 445 | 515 | 3.0 | 445 | 515 | 3.0 | 185 |
| 115,000 | 115.0 | 540 | 625 | 3.0 | 540 | 625 | 3.0 | 231 |
| 138,000 | 138.0 | 645 | 750 | 3.0 | 645 | 750 | 3.0 | 277 |
| 161,000 | 161.0 | 750 | 870 | 3.0 | 750 | 870 | 3.0 | 323 |
| 196,000 | 196.0 | 900 | 1,055 | 3.0 | 900 | 1,055 | 3.0 | 393 |
| 230,000 | 230.0 | 1,050 | 1,210 | 3.0 | 1,050 | 1,210 | 3.0 | 461 |
| 287,500 | 287.5 | 1,290 | 1,495 | 3.0 | 1,290 | 1,495 | 3.0 | 576 |
| 345,000 | 345.0 | 1,540 | 1,785 | 3.0 | 1,540 | 1,785 | 3.0 | 691 |

* These circuit voltages are those agreed upon by the "NEMA-NELA Preferred Voltage Ratings for A-C Systems and Equipment," NELA publication No. 043, page 12, and supplemented by the AIEE transformer subcommittee, Electrical Engineering, January 1937, page 32, table I.

** These values represent the maximum transformer voltage rating normally associated with the corresponding insulation level. These figures may be used to designate the insulation class.

pressed in terms of gap spacing, the following percentages apply:

| | | |
|---|---|---|
| Basic insulation level | = | 100 per cent |
| Applied voltage—chopped wave test | = | 110 per cent |
| Applied voltage—full wave test | = | 95 per cent |

When the impulse flashover of the bushing is higher than the required minimum standard of 105 per cent of the test gap flashover, as for power transformers 69 kv and below, the applied voltage for the chopped wave and full wave test is 105 per cent and 90 per cent respectively of the actual bushing flashover voltage recommended as standard.

In table II a minimum time to flashover is given. This is to insure a reasonable length of wave so as to retain the severity of the present tests.

## Insulation Level

### Distribution (500 Kva and Less) Transformers Power (Larger Than 500 Kva) Transformers

*A. Insulation Level*

1. Table II gives the proposed standard relationship between the established rated circuit voltages and corresponding limits of rated transformer voltage, and the standard insulation level for distribution (500 kva and less) and power (larger than 500 kva) transformers.

2. The standard insulation levels are expressed in terms of the full wave impulse test voltage, the chopped wave impulse test voltage with minimum time to flashover, and the low-frequency test voltage. The impulse test voltage is the crest value of the standard 1.5x40 microsecond impulse test wave.

*B. Choice of Insulation Level*

1. The insulation level for a given installation should be selected in accordance with the operating conditions, the volt-time performance characteristic of the protective equipment, and economics.

### Bushing Characteristics

1. Table III gives the minimum impulse flashover voltage (full wave) with the positive 1.5x40 microsecond wave, and the guaranteed 60-cycle dry and wet flashover voltage, for distribution and power transformers. These values are for standard atmospheric conditions.

2. The impulse flashover voltage and the guaranteed 60-cycle flashover voltages are subject to a tolerance of minus 5 per cent.

To keep the impulse flashover voltage of transformer bushings 5 per cent above the impulse flashover of the transformer test gap, a slight revision in bushing characteristics is being considered. All changes have resulted in slight increases in bushing impulse flashovers.

### Bushing Gaps

The practice of supplying transformers with bushings gapped to meet the recommended flashover standards has been in use some 3 years or so. It has been maintained by some users of such transformers that the gaps are undesirable in many cases, particularly in the lower voltage power transformer class. It would be particularly helpful to the transformer subcommittee to get the opinion of others on the desirability of equipping transformer bushings with gaps.

**Table III. Bushing Characteristics—Distribution and Power Transformers**

| | | Bushing Flashover in Kilovolts | | | | | |
|---|---|---|---|---|---|---|---|
| | | Distribution Trans. 500 Kva and Smaller | | | Power Transformers Larger than 500 Kva | | |
| | | | 60-Cycle Guaranteed Flashover | | | 60-Cycle Guaranteed Flashover | |
| Rated Circuit Voltage (Volts) | Limit of Rated Trans. Voltage (Kv) | Impulse* Flash-over Average | Dry | Wet | Impulse* Flash-over Average | Dry | Wet |
| 120, 240, 480, 600 | 1.2 | 34 | 11 | 7 | 66 | 25 | 12 |
| 2,400, 2,500 | 2.5 | 56 | | | | | |
| 4,160, 4,330, 4,800 | 5.0 | 66 | 27 | 18 | 84 | 40 | 27 |
| 6,900 | 8.66 | 84 | 40 | 27 | 105 | 50 | 35 |
| 11,500, 13,800 | 15.0 | 110 | 53 | 37 | 125 | 65 | 45 |
| 25,000 | 25.0 | 158 | 78 | 55 | 170 | 85 | 60 |
| 34,500 | 34.5 | 200 | 110 | 80 | 215 | 115 | 85 |
| 46,000 | 46.0 | 265 | 140 | 105 | 275 | 150 | 120 |
| 69,000 | 69.0 | 375 | 205 | 155 | 385 | 215 | 165 |
| 92,000 | 92.0 | 500 | 280 | 210 | 500 | 280 | 210 |
| 115,000 | 115.0 | 600 | 340 | 260 | 600 | 340 | 260 |
| 138,000 | 138.0 | 715 | 405 | 310 | 715 | 405 | 310 |
| 161,000 | 161.0 | 825 | 460 | 355 | 825 | 460 | 355 |
| 196,000 | 196.0 | 1,000 | 555 | 430 | 1,000 | 555 | 430 |
| 230,000 | 230.0 | 1,155 | 640 | 500 | 1,155 | 640 | 500 |
| 287,500 | 287.5 | 1,430 | 760 | 610 | 1,430 | 760 | 610 |
| 345,000 | 345.0 | 1,705 | | | 1,705 | | |

* $1\frac{1}{2}$x40 microsecond positive full wave.

## Proposed Standard Impulse Tests

### Impulse Test

A proposal is being considered to simplify the present impulse test code as follows:

The standard impulse test shall consist of 2 applications of a specified chopped wave followed by one application of a full wave. Either a positive or a negative wave may be used. The chopped wave may be obtained by flashing over either the bushing or an external rod gap.

1. *Chopped Wave.* For this test the applied voltage wave shall have a crest voltage and time to flashover in accordance with table II, columns 4 and 5 or columns 7 and 8 respectively for distribution transformers (500 kva and less) or power transformers (larger than 500 kva) respectively.

2. *Full Wave.* For this test the applied voltage wave shall have a crest value in accordance with table II, column 3 or column 6 for distribution and power transformers, respectively. For this test bushing gaps may be removed and negative wave can be used.

## Standard Low-Frequency Tests

The standard low-frequency test consists of an applied potential test followed by an induced potential test.

1. *Applied Potential Test.* The applied potential test shall be made by applying between each winding successively and ground, a low-frequency alternating voltage from an external source in accordance with table II, column 9. All other electric circuits and metal parts shall be grounded during the test.

2. *Induced Potential Tests.* The induced potential test shall be made by applying between the terminals of one winding a voltage of twice the normal voltage developed in that winding.

If testing circuit conditions are such that the induced voltage test just described does not at the same time produce twice the rated voltage of the circuit between adjacent line terminals of a 3-phase transformer an additional test with the same or other circuit connections shall be made to produce this voltage between line terminals.

## Bibliography


1. Dielectric Strength of Transformer Insulation, P. L. Bellaschi and W. L. Teague. Electrical Engineering, volume 56, January 1937, pages 164–71, 137.

2. Proposed Transformer Standards, J. E. Clem. Electrical Engineering, volume 56, January 1937, pages 32–6.

3. Discussion of the paper by V. M. Montsinger, entitled "Breakdown Curve for Solid Insulation," P. L. Bellaschi and W. L. Teague. Electrical Engineering, volume 55, April 1936, pages 399–402.

4. Impulse Voltages Chopped on Front, P. L. Bellaschi. Electrical Engineering, volume 55, September 1936, pages 985–90.

5. Breakdown Curve for Insulation, V. M. Montsinger. Electrical Engineering, volume 54, December 1935, page 1300.

6. Adequate Impulse Tests; Discussion of the Surge Tests Proposed by the Transformer Subcommittee of the AIEE, F. J. Vogel. *Electric Journal*, volume 32, January 1935, pages 29–30.

7. Deplores Trend in Insulation Co-ordination, F. J. Vogel. *Electrical World*, volume 105, January 19, 1935, page 216.

8. Factors Influencing the Insulation Co-ordination of Transformers—Part II, P. L. Bellaschi and F. J. Vogel. Electrical Engineering, volume 53, June 1934, pages 870–6. Discussion, volume 53, October 1934, pages 1401–07.

9. Recommended Transformer Standards, H. V. Putman and J. E. Clem. Electrical Engineering, volume 53, December 1934, pages 1594–7. Discussion, volume 54, July–September 1935, pages 770–1, 887–8, 985–6.

10. Making a Transformer Surge Proof, P. L. Bellaschi. *Electric Journal*, volume 30, December 1933, pages 493–5.

11. Measurement of High Surge Voltages, P. L. Bellaschi. AIEE Transactions, volume 52, June 1933, pages 544–67.

12. Surge Testing Potential Transformers, W. M. Dann. *Electric Journal*, volume 30, April 1933, pages 145–6.

13. Impulse Voltage Testing, C. F. Harding and C. S. Sprague. AIEE Transactions, volume 52, June 1933, pages 428–33. Discussion, page 440, and Electrical Engineering, volume 52, October 1933, pages 678–82.

14. Co-ordination of Insulation, V. M. Montsinger and others. AIEE Transactions, volume 52, June 1933, pages 417–27.

15. Effect of Excitation on Surge Stresses, F. J. Vogel. *Electric Journal*, volume 30, July 1933, pages 293–4.

16. Voltage Protective Devices on Stresses in Power Transformers, K. K. Palueff and J. H. Hagenguth. AIEE Transactions, volume 52, September–December 1933, pages 954–72.

17. Progress Report in Impulse Testing of Commercial Transformers, F. J. Vogel and V. M. Montsinger. AIEE Transactions, volume 52, June 1933, pages 409–10. Electrical Engineering, volume 52, January 1933, pages 9–11.

18. Recommendations for Impulse Voltage Testing, AIEE Transactions, volume 52, June 1933, pages 466–74.

19. Shunt or Insulated Transformers. *Electrical World*, volume 101, February 11, 1933, page 203. Discussion, volume 101, March 4, pages 302–03; April 22, 1933, page 526.

20. New Surge Generator for Testing Transformers, O. Ackerman. *Electric Journal*, volume 29, February 1932, pages 61–3.

21. Co-ordination of Transformer Insulation With Line Insulation, V. M. Montsinger and W. M. Dann. Electrical Engineering, volume 51, June 1932, pages 390–1. AIEE Transactions, volume 51, December 1932 pages 923–4.

22. Impulse Testing of Large Transformers, F. D. Newburg. Electrical Engineering, volume 51, April 1932, pages 252–4.

23. Transient Voltage Stresses in Power Transformers, K. K. Palueff *Engineering*, London, volume 153, May 13–20, 1932, pages 519–20, 551–3.

24. Impulse Testing With Dynamic Power Connected, H. V. Putman *Electrical World*, volume 99, April 9, 1932, pages 660–2.

25. Insulation Co-ordination of Distribution Transformers, E. D. Treanor and W. H. Cooney. AIEE Transactions, volume 51, December 1932, pages 925–35.

26. Factors Influencing the Insulation Co-ordination of Transformers, F. J. Vogel. AIEE Transactions, volume 52, June 1932, pages 411–16.

27. Impulse Voltage Testing of Power Transformers, F. J. Vogel. *Electric Journal*, volume 29, April 1932, pages 161–4.

28. Transformer Insulation Tests, L. Wetherill. *G. E. Review*, volume 35, December 1932, pages 649–53.

29. New Power Transformer Withstands Lightning Surges, W. M. Dann. *Electric Journal*, volume 28, December 1931, pages 657–9.

30. Standards of Insulation and Protection for Transformers, J. A. Johnson and E. S. Bundy. AIEE Transactions, volume 49, October 1930, pages 1486–90. *Electrical World*, volume 96, July 5, 1930, pages 24–5 (condensed).

31. Recommendations on Balancing Transformer and Line Insulation on Basis of Impulse Voltage Strength, V. M. Montsinger and W. M. Dann. AIEE Journal, volume 49, November 1930, pages 934–7. AIEE Transactions, volume 49, October 1930, pages 1478–81. (Includes a reference list of 5 items.)

32. Essential Factors in the Co-ordination of Line Station and Apparatus Insulation, A. E. Silver and H. L. Melvin. AIEE Transactions, volume 49, October 1930, pages 1491–1513. (With an extensive discussion including the problem of transformer insulation.)

33. Lightning Studies of Transformers by the Cathode-Ray Oscillograph, F. F. Brand and K. K. Palueff. AIEE Journal, volume 48, July 1929, pages 542–6.

34. Effect of Surges on Transformer Windings, J. K. Hodnette. AIEE Journal, volume 48, November 1929, pages 829–932.

35. Surge vs. Impulse Tests for Transformers, V. M. Montsinger and J. F. Peters. *Electrical World*, volume 93, June 22, 1929, pages 1275–7.

36. Effect of Transient Voltages on Power Transformer Design, K. K. Palueff. AIEE Transactions, volume 48, July 1929, pages 681–706.

37. Relation Between Transmission Line Insulation and Transformer Insulation, W. W. Lewis. AIEE Transactions, volume 47, October 1928, pages 992–7. AIEE Journal, volume 47, September 1928, pages 637–40 (abridgment).

38. Effects of Time and Frequency on Insulation Test of Transformers, V. M. Montsinger. AIEE Transactions, volume 43, 1924, pages 337–47.

39. Insulation Tests of Transformers as Influenced by Time and Frequency, F. J. Vogel. AIEE Transactions, volume 43, 1924, pages 348–55.


**Night view of the new Court House at Milwaukee, Wis., scene of the Institute's forthcoming summer convention**

# News

## Of Institute and Related Activities

## The AIEE Summer Convention This Month at Milwaukee, Wis.

ALL ARRANGEMENTS have been made for the fifty-third annual summer convention which will be held at Milwaukee, Wis., June 21–25, 1937, with headquarters in the Schroeder Hotel. The summer convention committee, under the chairmanship of K. L. Hansen, has arranged an attractive program of sports, inspection trips and entertainment built around the annual business meeting, 10 technical sessions, and 1 general session. The convention also affords opportunity to combine business with a few days vacation. For a more complete account of the convention features, including a schedule of events and the tentative technical program, see ELECTRICAL ENGINEERING for May, pages 635–9.

### Technical Program

The tentative technical program as announced in the above reference is complete with the following changes. The paper "Approximating Potier Reactance" by Sterling Beckwith, Allis-Chalmers Manufacturing Co., has been added to the session on power generation and electrical machinery scheduled at 10:00 a.m., Thursday, June 24. The date for scheduling the conference on field problems has been interchanged with the date for scheduling the conference on electrical apparatus for 3-phase arc furnaces. The programs for these conferences are as follows:

#### Wednesday, June 23

2:30 p.m.—Conference on Field Problems, Ernst Weber, presiding

1. Introduction: The field concept in physics and engineering
2. Topics:
   (*a*) Graphical field plotting (special applications to magnetic fields)
   (*b*) Analytical solutions of fields (special applications to heat problems)
   (*c*) Conformal representation (special applications to electric fields)
   (*d*) Experimental methods of field exploration (special applications to hydrodynamics)

#### Thursday, June 24

2:30 p.m.—Conference on Electrical Apparatus for 3-Phase Arc Furnaces

1. Introduction: Modern arc furnace apparatus—lantern slides—Samuel Arnold
2. Discussions:
   (*a*) Kilovolt-ampere ratings—Frank Brooke
   (*b*) Voltages—C. C. Levy
   (*c*) Reactance—F. V. Andreae
   (*d*) Regulation—F. E. Ackley
   (*e*) Protective equipment—E. L. McClure
   (*f*) Methods of supplying power—L. W. Clark

### Doctor Vannevar Bush to Speak

One of the high lights of the summer convention will be a lecture Tuesday evening by Doctor Vannevar Bush on the subject "The Engineer and His Relation to Government." This meeting very appropriately precedes the general session Wednesday morning on economic aspects of engineering and Institute activities.

This evening lecture will be open to the public, fellow-engineers from other founder and local societies and the ladies as well. The Engineers' Society of Milwaukee has already chosen to dispense with its regular June meeting and join with the Institute on this occasion. Special plans are also being made for groups to come from Chicago and Madison for this evening lecture.

Vannevar Bush

Doctor Vannevar Bush is noted for his achievements in research and his contributions to engineering progress and to technical education. For the development of the product integraph he was awarded the Levy Medal of the Franklin Institute in 1928. For "his development of methods and devices for application of mathematical analysis to problems of electrical engineering" he was awarded the AIEE Lamme Medal for 1935. He has lectured at Cambridge, England, at the International Congress of Applied Mechanics and he has delivered the Josiah Willard Gibbs lecture of the American Mathematical Society. Doctor Bush designed the differential analyzer and under his direction the network analyzer at Massachusetts Institute of Technology was built. He is also known for his contributions to the development of vacuum tubes and for his investigations in electric power transmission, transients in machines, and dielectric phenomena.

The career of Doctor Bush as a teacher has been no less notable than his work in research and in 1932 he was appointed vice-president and dean of the school of engineering of the Massachusetts Institute of Technology.

### Sports

Excellent facilities will be available for golf and tennis enthusiasts. Golf events will include competition for the Mershon, Lee, and District Team Trophies and special events. Golf on Monday and Tuesday will be on the course of the Tripoli Country Club, on Wednesday and Thursday at the Ozaukee Country Club, and on Friday at the Bluemound Golf and Country Club. Qualifying play for the Mershon Trophy, which is on a handicap basis, will be on Monday with match play rounds on Tuesday, Wednesday, and Thursday. The Lee Trophy in golf which is on a handicap basis, 36 holes of medal play, will be on Monday and Tuesday.

The District team event, the winner of which is decided on the basis of the gross medal score for the 4 lowest out of a team of 6 players from each District for 36 holes will be played Monday and Tuesday. It is suggested that each District organize a team before leaving for the convention.

The annual tennis tournament for the Mershon Tennis Trophy will be held on the clay courts of the Milwaukee University School. Numerous prizes for both golf and tennis have been provided and these will be awarded at the informal farewell dinner to be held Friday evening at the Bluemound Golf and Country Club.

In order to facilitate imposing fair handicap, the sports committee has requested that those who intend to play golf furnish the following information: average of their 5 best scores in 1936; par of their regular courses.

### Women's Entertainment

While the men are busily engaged in the technical sessions and inspection trips the women will not be overlooked. A committee, under the leadership of Mrs. A. C. Flory, has provided a wide variety of interesting and entertaining events. These include a varied assortment of parties, a tea, luncheon, inspection and shopping trips, golf, and a day at a country club. These, of course, are in addition to the combined events—the boat trip on Lake Michigan, the trip to the Schlitz Brewery, president's reception and dinner dance Thursday evening, and the farewell party at the Bluemound Golf and Country Club Friday night. The aim of the women's committee is to make every woman visitor feel Milwaukee's traditional and gracious hospitality and to let no one leave the convention without learning the real meaning of *gemutlichkeit* (see May 1937 issue, page 638).

## Institute Prize Awards Announced for 1936 Papers

The committee on award of institute prizes has announced the award of 4 national prizes for papers presented during the calendar year 1936. Personal presentation of the prizes will take place during the summer convention to be held in the Hotel Schroeder, Milwaukee, Wis., June 21–25, 1937. The personnel of the committee consists of H. S. Osborne (A'10, F'21), *chairman*, O. W. Eshbach (A'17, M'30), W. B. Kouwenhoven (A'06, F'34), W. R. Smith (M'18, F'30), and I. Melville Stein (A'18, M'27).

Rules governing the award of future prizes were published in Electrical Engineering for April 1937, page 492. In accordance with these rules, papers for the District Branch paper prize and the newly established graduate student prize, will be awarded on the basis of the academic year, and must be submitted on or before July 15, 1938. The Branch papers which have been presented from January to June 1937, may also be submitted at that time for consideration.

### National Prizes

After due consideration of all highly recommended papers, the committee on award of Institute prizes made the following awards of national prizes for papers presented in 1936:

#### Best Papers

*Best Paper in Engineering Practice.* This prize was awarded to P. S. Millar (A'03, M'13) for his paper "The Qualities of Incandescent Lamps," published in Electrical Engineering for May 1936, pages 516–23, and discussed at the summer convention, Pasadena, Calif., June 22–26, 1936.

Honorable mention was made of the following papers: "The Relation between Load, Capacity, and Service Continuity on an Electric Power System" by W. J. Lyman (A'25), presented before the Pittsburgh Section, December 8, 1936; "Modernization of Power Distribution Systems" by H. P. Seelye (A'19, M'28), published in Electrical Engineering for January 1936, pages 75–84, and discussed at the winter convention, New York, N. Y., January 28–31, 1936.

*Best Paper in Theory and Research.* This prize was awarded to H. E. Edgerton (A'27, M'32) for his paper "High Speed Motion Pictures," published in Electrical Engineering for February 1935, pages 149–53, and discussed at the winter convention, New York, N. Y., January 28–31, 1936.

Honorable mention was made of the following papers: "Pull-In Characteristics of Synchronous Motors" by D. R. Shoults (A'35), S. B. Crary, Jr. (A'31), and A. H. Lauder (A'24), published in Electrical Engineering for December 1935, pages 1385–95, and discussed at the winter convention, New York, N. Y., January 28–31, 1936; "Laboratory Studies of Conductor Vibration" by J. S. Carroll (A'24), published in Electrical Engineering for May 1936, pages 543–7, and discussed at the summer convention, Pasadena, Calif., June 22–26, 1936.

*Best Paper in Public Relations and Education.* In view of the fact that only 2 papers eligible for this prize were presented last year the committee deemed it advisable to make no award under this classification. Under the rules these 2 papers will be eligible for consideration the next time prizes are awarded.

#### Initial Paper

Prize for initial paper was awarded to D. H. Rowland (A'26) for his paper "Porcelain for High Voltage Insulators," published in Electrical Engineering for June 1936, pages 618–26, and discussed at the summer convention, Pasadena, Calif., June 22–26, 1936.

Honorable mention was made of the following papers: "Induction Heating at Low Temperatures" by E. L. Bailey (A'19, M'25), published in Electrical Engineering for November 1935, pages 1210–12, and discussed at the winter convention, New York, N. Y., January 28–31, 1936; "Earth Resistivity and Geological Structure" by R. H. Card (A'22, M'35), published in Electrical Engineering for November 1935, pages 1153–61, and discussed at the winter convention, New York, N. Y., January 28–31, 1936.

#### Branch Paper

Prize for Branch paper was awarded to W. James Walsh for his paper "Heat Transfer Efficiency of Electric Range Surface Units," presented at a joint meeting of the Portland Section and Oregon State College Branch, AIEE, Corvallis, Ore., May 16, 1936.

Honorable mention was made of the following papers: "A Direct Reading Linear Accelerometer" by Harry B. Fuge, presented at a meeting of the Polytechnic Institute of Brooklyn Branch, AIEE, April 1936; "Tidal Power," by D. R. Barney, presented at the annual student convention District No. 3, AIEE, New York, N. Y., April 22, 1936; "A High-Speed Vibration Analyzer," by William R. Harry, presented at the North Eastern District Meeting, New Haven, Conn., May 6–9, 1936; "Frequency Multipliers," by Ronald F. Huminski and Everard M. Williams, presented at the North Eastern District Meeting, New Haven, Conn., May 6–9, 1936.

The committee has considered all the eligible papers and in connection with papers in all classifications except Branch papers had the benefit of the recommendations of the technical committee chairmen relative to the best papers in their respective fields.

### District Prizes

District prizes as announced by 4 Districts to date include 3 awards of $25 each, together with appropriate certificates. Other District awards will be announced later, as the information becomes available.

#### District 1

Prize for best paper was awarded to E. M. Hunter (A'28, M'36) for his paper "Tests on Lightning Protection for A-C Rotating Machines," published in Electrical Engineering for February 1936, pages 137–44, and discussed at the North Eastern District Meeting, New Haven, Conn., May 6–9, 1936.

Prize for initial paper was awarded to E. A. Harty (A'22, M'36) for his paper "Aging in Copper Oxide Rectifiers," presented at the North Eastern District Meeting, New Haven, Conn., May 6–9, 1936.

Prize for Branch paper was awarded to W. R. Harry for his paper "A High-Speed Vibration Analyzer," presented at the North Eastern District Meeting, New Haven, Conn., May 6–9, 1936.

#### District 2

Prize for initial paper was awarded to A. C. Herweh for his paper "An Open Arc Type of Stroboscope," presented before a joint meeting of the Cincinnati Section and University of Cincinnati Branch, AIEE, May 19, 1936.

#### District 7

Prize for Branch paper was awarded to J. H. Treadwell for his paper "A Rotating Ball Slip Meter," presented at the South West District Meeting, Dallas, Texas, October 26–28, 1936.

#### District 9

Prize for Branch paper was awarded to W. James Walsh for his paper "Heat Transfer Efficiency of Electric Range Surface Units," presented at a meeting of the Oregon State College Branch, AIEE, Corvallis, Ore., May 16, 1936.

**ASTM Annual Meeting.** The fortieth annual meeting and fourth exhibit of testing apparatus and related equipment of the American Society for Testing Materials will be held in New York, N. Y., from June 28 to July 2, 1937, with headquarters at The Waldorf-Astoria Hotel. A program of entertainment and inspection trips will supplement the technical program. Many companies will display and demonstrate the latest developments in instruments for various phases of the production, control, and testing of materials and products of all kinds. Certain educational and research institutions will also be invited to display special equipment and devices which they have developed for unusual testing and research in the materials fields.

## Coast IRE and AIEE Plan Joint Convention at Spokane

An innovation in Pacific Coast convention procedure that is being enthusiastically developed by the local committees in charge will bring together for a concurrent convention in Spokane, Wash., the Pacific Coast members of the Institute of Radio Engineers and of the AIEE. The annual Pacific Coast AIEE convention is scheduled to be held from August 30 to September 3, inclusive. The IRE Pacific Coast convention, the first to be held, is scheduled for September 1 and 2.

Plans in progress as announced by the committee in charge provide for a joint technical session to be held September 2, to which both AIEE and IRE members will contribute technical papers of common interest. Other sessions of the AIEE Pacific Coast convention program will be held as usual, and separate technical sessions are being planned by the radio engineers.

## 1937 Lamme Medal Nominations Due Nov. 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the Lamme Medal, to be awarded in the fall of 1937, may be submitted by any member in accordance with Section 1 of Article VI of the by-laws of the Lamme Medal committee, as quoted in the following:

> The committee shall cause to be published in one or more issues of Electrical Engineering, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by November 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least 3 engineers of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the

achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specified specific information should be given regarding his individual contributions. Names of endorsers should be given as specified above.

The Lamme Medal, founded as a result of a bequest of the late Benjamin Garver Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company (deceased July 8, 1924), provides for the annual award by the Institute of a gold medal—together with bronze replica thereof—to a member of the AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery"; and for the award of 2 such medals in some years if the accumulation of funds warrants.

The ninth (1936) Lamme Medal has been awarded to Doctor Frank Conrad (A'02, F'37), assistant chief engineer of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., "for his pioneering and basic developments in the fields of electric metering and protective systems." Presentation will be made during the AIEE summer convention at Milwaukee, Wis., June 21–25, 1937. A biographical sketch of Doctor Conrad appeared in ELECTRICAL ENGINEERING for March 1937, pages 395–6.

## Additions to Member-for-Life List

Membership for life is granted by the Institute for either of the following 2 reasons: a member has paid annual dues for 35 years; or has reached the age of 70 and has paid dues for 30 years.

The fiftieth anniversary issue of ELECTRICAL ENGINEERING published in May 1934 and the September 1935 number included lists of all members who had been enrolled upon the Institute records as Members for Life during the period up to May 1, 1935. Those who became Members for Life between 1935 and 1936 were listed in the June 1936 issue.

The list that follows indicates those members who have become Members for Life since the publication of the list in the June 1936 issue:

Addicks, L.
Aitken, William
Atkinson, A. A.
Atkinson, W. S.
Averrett, A. E.
Barnes, W. J.
Beam, Victor S.
Bell, A. C.
Bennett, Edward
Bennett, W. S.
Blakeslee, H. J.
Brown, Carlton E.
Brown, R. C.
Brown, W. E.
Butler, W.
Carpenter, H. C.
Coldwell, O. B.
Conwell, W. L.
Cowles, J. W.
Dick, W. A.
Dixon, James
Dodge, K.
Edmonston, E. D.
Eglinton, W. M.
Erwin, F. B.
Everit, E. H.
Feldmann, C.
Ferguson, L. A.
Ferguson, S.
Firman, L. D.
Foster, W. J.
Gear, H. B.
Gibson, J. J.
Gill, Frank
Graham, W. P.
Graling, V.
Harisberger, J.
Hodgkinson, F.
Hunt, F. L.
Keller, C. A.
Kingsbury, Albert
Kruesi, P. J.
Lanphier, R. C.
Lesley, Hugh
Leyden, H. R.
Lillibridge, R. D.
Lincoln, J. C.
Lowenberg, L.
Magie, L. D.
Manville, C. B.
Marburg, L. C.
McAllister, A. S.
McGrath, W. H.
Medbery, S. C., Jr.
Moody, W. S.
Morris, J. W.
Nash, L. R.
Pearson, E. R.
Pierce, A. L.
Potts, L. M.
Pratt, W. H.
Rea, N. L.
Reber, H. L.
Reynolds, W. H.
Roberts, T. M.
Rosenthal, L. W.
Ruckgaber, A. F.
Ruffner, C. S.
Rugg, W. S.
Sage, D.
Sawyer, W. H.
Schildhauer, E.
Schluederberg, C. G.
Smith, F. W.
Smith, W. N.
Soren, T. H.
Sporborg, H. N.
Stevenson, F. L.
Storer, S. B.
Stovel, R. W.
Tuttle, H. B.
Van Dyck, W. V.
Waddell, C. E.
Wagoner, P. D.
Waldo, E. H.
Warren, H. E.
Waters, W. L.
White, F. J.
Whittemore, G. W.
Wilder, S.
Wilson, R. L.
Winslow, C. G.

## AIEE Sections Members of Indiana Engineering Council

Growing out of a reorganization of the Indiana Engineering Society, the Indiana Engineering Council has been formed to function in the State in the same manner in which the American Engineering Council functions nationally. The Indiana Engineering Society was in operation for many years, and was composed principally of members of the 3 national societies: American Society of Civil Engineers, American Society of Mechanical Engineers, and the AIEE. This society was an incorporated body with the objective of bringing together these engineers and the land surveyors of the State to encourage professional intercourse and the development and advancement of its membership.

In the opinion of the officers of this society it would serve its purpose better if organized in the manner of American Engineering Council. Accordingly, at the last annual meeting of the society held February 16, 1937, and through the counsel of Dean A. A. Potter of Purdue University, president of AEC, steps for a reorganization were taken which resulted in the formation of the Indiana Engineering Council.

Both the Central Indiana and the Fort Wayne AIEE Sections are participating in the new organization.

According to Foster L. Stanley, chairman of the AIEE Central Indiana Section, who supplied the information for this news item, organization plans are now being developed by the following officers:

**President:** M. R. Keefe, chief engineer, Indiana State Highway Commission.

**Vice-President:** F. R. Weaver, vice-president, ASME, and an influential engineer in the State.

**Secretary-Treasurer:** Homer Ruppard, assistant chief engineer, Indianapolis Water Company.

**Executive Board:** Harry O. Garman (A'08, M'23) consulting engineer, past-president of the Indiana Engineering Society and past-chairman of the Central Indiana Section (1917–18). Charles Brossman (M'28) chief engineer, Indianapolis Water Company; Professor F. C. Hockema, assistant to president of Purdue University, chairman Central Indiana Section, ASME; Foster L. Stanley (A'34) plant extension engineer, Indiana Bell Telephone Company.

**Map of Illinois Lines.** A comprehensive map of electric transmission and distribution lines in Illinois has been prepared by the state rural electrification committee which shows all rural electric lines, transmission lines, points of interconnection, generating stations, and other electric facilities. All lines built up to January 1, 1937, are included. Copies of the map are printed in 3 colors and 30 inches by 50 inches in size may be obtained directly from the State Rural Electrification Committee, 220 Centennial Building, Springfield, Ill., at nominal cost.

## Membership—

Mr. Institute Member:

Vacation season is here! Many of our Sections have held their last meeting until fall and the membership committees have done the major portion of their work. They have done well too for the AIEE has the largest membership reported for the past 4 years, as of May first.

Now is the time when the help of the Institute members is most needed in membership work. Do not wait until fall to get your prospective member an application blank, but send his name to New York headquarters if your local membership committee is away on vacation. Your prospect will appreciate being "in" on the beginning of the new Section year and the Institute will appreciate your co-operation.

Fred B. Doolittle

Vice-Chairman, District No. 8
National Membership Committee

# Industrial Applications and Power System Problems Discussed at Buffalo—Students Also Hold Busy Session

A DISTINCTLY industrial flavor was one of the more attractive features of the AIEE North Eastern District meeting held May 5–7 at Buffalo, N. Y. Supplementing and giving point to 2 special informal papers that were devoted to a discussion and explanation of current trends in the design and application of the electrical equipment that is playing so vital a part in modern steel-mill electrification, was a correlated inspection trip through the new 72-inch continuous hot- and cold-strip mill of the Bethlehem Steel Company at nearby Lackawanna.

That lightning still holds its interest for power system operating engineers, electrical equipment manufacturers, and others was evidenced by the scope and character of the active discussion resulting from the presentation of 3 papers pertaining in one way or another to this subject. Other power-system problems were touched upon by papers describing the operating performance of a relay protective system for a large interconnected power system, operating performance of one of the newer steam-electric generating stations, experimental study of "dancing" cables, and the organization and operating procedure incident to the conduct of research and test work by 2 large electric utilities. An interesting informal paper describing the steps involved in surveying telephone requirements for a large industrial or commercial user gave an insight into some of the engineering and traffic problems incident to the modern facility of communication that today is taken very much for granted.

President MacCutcheon was an interested and active participant in practically all phases of the District meeting program. Presiding at the various sessions were: C. T. Sinclair, Pittsburgh, Pa., opening session; Robert Treat, Schenectady, N .Y., first general session; R. W. Graham, Lackawanna, N. Y., second general session; D. C. West, Buffalo, dinner meeting. J. Leo Scanlon, chairman of the Niagara Frontier Section, Buffalo, acted on behalf of the Section as host and general factotum.

### Steel Mill Electrification

Speaking on "Design Trends in Steel Mill Electrification," L. A. Umansky (A'16, M'27) of the General Electric Company, Schenectady, N. Y., graphically illustrated and dramatically described the ever-increasing extent to which modern sheet-steel production is directly dependent upon electric driving and controlling mechanisms. He pictured briefly the evolution of sheet rolling from the old simple single stand for sheets now regarded as small, to a modern mill where sheets 100 feet or more in length pass simultaneously through several rolls in tandem, to emerge at speeds of from 1,200 to 2,000 feet per minute. The intricacy and the importance of the electric driving and controlling equipment involved in such an operation can be understood when it is realized that each successive stand of rolls operates at a different speed in accordance with the progressive elongation of the strip, all being interlocked to maintain a predetermined setting.

Mr. Umansky's talk served also to emphasize the decisiveness of a trend, noted also in other branches of industry, toward an increasingly wider use of d-c machinery, because of its flexibility and susceptibility to precise control.

F. D. Egan (M'34) of the Bethlehem Steel Company described in some detail the "electrical applications" in that company's 72-inch continuous hot- and cold-strip mill at Lackawanna, N. Y. Although other mills now are under construction, this is one of the newest of the large mills now in operation, and is regarded as a typical example of a modern electrified steel mill. It has an annual capacity of 800,000 tons of hot-rolled strips, sheets, and light plates, of which 360,000 tons can be converted into cold-rolled finished products, and is capable of producing strips up to 72 inches in width by 0.078 inch in thickness, as well as light plates up to $^1/_2$ inch in thickness. It is designed to handle stock slabs ranging from 20 to 40 inches in width, from 3 to 6 inches in thickness, and from 5 to 15 feet in length.

**R. W. Graham of Lackawanna, N. Y., presided at one of the general sessions**

Electrically as well as mechanically, heavy-duty equipment is a prominent characteristic of such a mill. Mr. Egan emphasized the vital importance of a continuity of electric service, pointing out that the power supply for the Lackawanna mill is obtained from 3 different sources over 6 lines from 2 different directions. One of the problems incident to serving the 22,500 horsepower of d-c finishing-mill motors was that, under short-circuit conditions, currents of the order of 300,000 amperes might be expected on the 600-volt d-c bus. Special designs were adopted, including wide separation of the positive and negative busses, to reduce or control the resulting tremendously heavy physical forces that would be exerted on the bus conductors and fittings under short-circuit conditions.

### Lightning

In areas where lightning prevails, it still appears on system operating records as the Number 1 cause of interruptions to electric-power circuits, as confirmed by the discussion of the subject at Buffalo. Consequently, there is a prevalent active interest in the subject, although the outward manifestation of the studies that have continued for so many years has shifted gradually from heated debates over conflicting theories to colder analyses of accumulating operating statistics and observed test data. Authorities seem pretty well agreed that, although effective progress has been made in the development of practical preventives or palliatives, further progress in the prevention or control of lightning disturbances on electric-power systems will come from extensive correlation of existing data as well as from a continuation of laboratory and field investigations.

I. W. Gross (A'12) of the American Gas and Electric Company, New York, N. Y. S. K. Waldorf (A'27, M'36) of the Pennsylvania Water and Power Company, Baltimore, Md.; and G. A. Powell (A'23) of the New York Power and Light Corporation, Albany, N. Y., presented, respectively, the following papers, which were published as noted in earlier issues of Electrical Engineering:

Lightning Currents in 132-Kv Lines, Philip Sporn and I. W. Gross. Published in February issue, pages 245–52.

Probable Outages of Shielded Transmission Lines, S. K. Waldorf. Published in May issue, pages 597–600.

Special Uses for the Automatic Oscillograph, G. A. Powell and R. E. Walsh. Published in April issue, pages 438–40.

These presentations, and the conclusions drawn by the authors, brought forth a variety of discussion. K. B. McEachron (A'14, M'20) of Pittsfield, Mass., commented at some length on the quantity and variety of statistical data that has been accumulated and now is available concerning the operation of electric power systems under lightning-storm conditions, the character of lightning strokes, the probability of lightning disturbances affecting a given line, and other aspects of the subject. He emphasized the present need for correlation among these various data and between them and weather-bureau data pertaining to the number of storm-days experienced in various areas. Discussing the question of ground resistance as it might affect the operation of equipment installed for protection against lightning damage, Mr. McEachron observed that data received from London, England, indicate definitely that the higher the tower the less important the matter of ground resistance becomes; this is because for very high towers the time required for the wave to travel down the length of the tower is enough to permit the wave to approach crest value at the tower top, thus causing flashovers.

W. F. Davidson (A'14, M'26) of the Brooklyn (N. Y.) Edison Company, urged that "further thought be given to the matter of 'silent discharges.'"

Speaking with reference to the "zone of protection," usually assumed to be afforded by a high grounded structure, S. K. Waldorf described troubles that had been experienced by a certain street railway company wherein flashovers occurred across insulators on which trolley feeders were supported from buildings along either side of a "downtown"

street flanked by buildings several stories high. He reported that a study of this situation indicated that lightning impulses were conducted down through the buildings to points where the resistance to ground was lower across the trolley-feeder insulators than it was down through the frame of the building, resulting in flashovers from building to trolley feeder and on to ground through railway equipment. An increase in the insulation at these points overcame the trouble.

Commenting on the characteristics of lightning, R. E. Walsh observed that waves resulting from lightning strokes "do not rise nearly as rapidly nor as steeply as some theories and some studies have indicated."

### Power System Operation

Four special presentations featured a general session devoted to power system problems:

Development and Operating Performance of a Relay System, L. J. Audlin (M'35), Syracuse, George Steeb (A'26, M'34), Buffalo, and G. A. Powell (A'23) of Buffalo, who constitute the relay committee of the Niagara-Hudson operating companies.

Operating Performance of C. R. Huntley Station. Presented in 2 parts: Electrical, J. M. Geiger (A'28, M'34); Mechanical, Donald Scranton; both of the Buffalo General Electric Company

Research and Testing in a Large Electric Utility, W. F. Davidson (A'14, F'26) director of research and test of the Consolidated Edison Company of New York, Inc.

Research and Testing in the Hydro-Electric Power Commission of Toronto, W. P. Dobson (A'13, M'19) chief testing engineer, Hydro-Electric Power Commission of Ontario, Canada.

These papers were developed especially for the Buffalo meeting, and have not been published in Electrical Engineering.

L. J. Audlin described briefly the operating, switching, and relaying problems involved in the gradual evolution of several distinct operating systems into what is in effect a single co-ordinated interconnected system covering a large portion of the State of New York. Extensive calculating-board studies of short-circuit conditions were described as having revealed the principal difficulties to be overcome for successful operation: that more rapid relay and circuit breaker operation would be required to avoid system instability; that phase relays would not provide adequate protection against certain types of ground faults. Replacements of circuit breaker and relay equipment have been effected until now about 44 per cent of the 140 or so switch positions on the interconnected transmission system are equipped with "distance" relays and high-speed oil circuit breakers (8-cycle) of heavy interrupting capacity. Further improvements now under way will bring this figure to about 54 per cent of the total line-switching positions. For main transmission circuits, differential protection (pilot relaying) for each individual circuit is considered to be the "ideal." This ideal is approached between the generating sources of the Niagara-Hudson power system and New York City by the supplemental use of carrier relay equipment for the control of directional relays. Operating records for the period 1933 to 1936 inclusive, showed a total of 1,185 disturbances, of which the 3 most prominent causes were: lightning, 56.1 per cent; sleet, wind, and jumping conductors, 12.4 per cent; and closing in on faults, 11.4 per cent. Relay operating records for the same period showed a total of 2,764 disturbances, of which 92.2 per cent were correct and desired, 5.3 per cent correct, but undesired, and 2.1 per cent incorrect or faulty, and 0.4 per cent failure to operate. A point raised for discussion was whether or not to separate 2 parts of an interconnected transmission system when synchronism is lost between them, some operating experiences indicating the possibility of re-establishing synchronism without interruption and without damage to equipment.

**Robert Treat of Schenectady, N. Y., presided at one of the general sessions**

The Huntley steam-electric generating station No. 2 was built in 1929, expressly for the purpose of providing for the change-over in the domestic and commercial load in the Buffalo area from 25-cycle to 60-cycle service. In describing the electrical operation of the station, J. M. Geiger pointed out that inasmuch as the bus bars of this one station would have to carry, for at least several years, all the 60-cycle energy for a large metropolitan area, provision for the highest order of reliability in the electrical equipment was a necessity. The station generating equipment comprises 2 8,000-kw 12,000-volt generators, each tied solidly to an autotransformer, the 22-kv windings of which normally are connected to opposite busses. This "split bus" scheme also is applied to the large transformers for the 110-kv transmission ties, for the frequency changer connections, and for the outgoing 22-kv feeders. The neutral leads of the generators and large transformers are connected to a common neutral bus and grounded through a 5-ohm resistor to limit fault currents to ground. Experiments with this resistor in service and out of service indicate that its use has no bearing on the rate of electric cable failures in the local system. Circuit arrangements and operating procedures were such, according to the report, that since the station was built there has not been a single interruption in the low-voltage-network service that is wholly dependent upon the station.

Research and test work are as vital to the effective and economical operation of the electric service utilities as they are to the success of other industrial enterprises. Descriptions of their respective organizations, methods of procedure, and types of work were given by W. F. Davidson of the Consolidated Edison Company of New York and W. P. Dobson of the Hydro-Electric Power Commission of Ontario. In Mr. Davidson's organization, all testing, except that involving mechanical equipment in generating stations, is assigned to the test bureau of the system engineering department. The scope of this department includes all testing of the transmission and distribution system and associated substations, all electrical equipment in the generating stations, maintenance of the standards laboratory and portable test instruments, and the testing of materials and such apparatus as require special laboratory facilities. The production department has a test organization in each generating station to handle the testing of mechanical equipment. A research bureau in the system engineering department is responsible for the conduct of research connected with the electrical operations (as distinguished from gas operations). To insure effective co-ordination of these separate agencies, the heads of research bureau and the test bureau report to the director of research and tests, and the station test groups report to the production economy engineer. These 2 men jointly handle those cases which concern more than one unit of the testing organization. For convenience and administration, the test bureau of the system engineering department is organized into 2 divisions: laboratory, and field tests, the names of which indicate the general scope of their activities and responsibilities. An important function of the laboratory division is the maintenance of reference standards. Another important function is the performance of acceptance tests on materials and apparatus. As to the research work, new problems constantly are arising, each to be dealt with in accordance with its requirements and importance.

**President A. M. MacCutcheon was an interested and active participant**

In the Hydro-Electric Power Commission of Ontario, the testing and research department is responsible for the testing and inspection of all materials and equipment purchased, and for the conduct of special investigations and research. W. P. Dobson pointed out that a comprehensive inspection and testing policy is followed and applied not only to new material and equipment, but also to material in service, with the object of detecting signs of failure and of devising remedial measures. Research problems are suggested by the difficulties encountered in construction and operation, and the work is carried on under the general direction of a research committee composed of 5 department heads. Projects are assigned to subcommittees containing representatives from all departments interested. Results accomplished were reported as including improved methods of operation, improved methods of treating materials to prolong their life, the development of new specifications or improvements of existing specifications for the purchase of materials, and the development of new equipment for special applications.

### Dancing Cables

"Dancing" or "galloping" cables on transmission and distribution lines have been observed under certain weather conditions for many years. At the Buffalo meeting, D. C. Stewart (A '25, M'35) assistant electrical engineer for the Buffalo, Niagara, and Eastern Power Corporation, presented the results of an experimental study of this condi-

tion. During dancing periods the cables had been observed to oscillate violently with amplitudes and motions of alarming proportions. As the cables do not move in synchronism, there is a resulting threat of contact or flashover and consequent interruption to service. Mr Stewart, in discussing the various theories that have been offered mentioned that propounded by A. E. Davison (A'13) of Toronto at the AIEE convention held in that city in June 1930 which was to the effect that the wind acting on irregular icy formations adhering to the cables exerts aerodynamic forces that initiate and maintain the cable motion. Mr. Stewart stated that although this theory failed to explain some cases where cable dancing has been reported when no ice was on the cable it does seem to account for the great bulk of reported cases. For his experimental span, Mr. Stewart reported the use of a 104-foot span of number 4 ACSR 7-strand cable strung at right angles to the direction of the prevailing wind. To this cable were affixed wax formations to simulate ice or snow deposits that had been observed under storm conditions when dancing prevailed. With special arrangements for observation and measurement, Mr. Stewart found that the cable on this test span under storm conditions swung in a path of approximately elliptical proportions and having a vertical axis of some 3 feet and a horizontal axis of some 2 feet, which swing carried the cable at midspan to a point considerably above the axis of support at the ends of the span. He found also that there was a periodic twisting of the conductor to the extent of more than 180 degrees above its longitudinal axis, as it swung in its elliptical path. With a wind velocity of about 61 feet per second, the cable traveled around its elliptical path at an average speed of some 14 feet per second. The experimental results reported were considered to confirm the theory that cable dancing results from wind blowing against irregular ice formations adhering to the cables; further, that the varying twists in the cable plays its part in the vibration phenomena. In the resulting discussion it was suggested that electromagnetic phenomena sometimes might be responsible for the initiation of vibration. The scope and character of this discussion indicated a broad interest in the problem as a possible cause of circuit interruption and seemed to indicate conclusively the desirability of further research and analysis.

### Student Technical Sessions

Although many students attended the other technical sessions, principal student attention was focused upon the session devoted to the presentation and discussion of the following student papers:

The Design, Construction, and Testing of a Miniature Cathode-Ray Oscilloscope, N. I. Korman, Worcester Polytechnic Institute.

A Transmission-Line Slide Rule, R. R. Gay and C. H. Hunter, Cornell University.

Television, D. O. Wood, Massachusetts Institute of Technology.

A High-Voltage Electrostatic Voltmeter, E. M. Williams (graduate student), Yale University.

Power-Circuit Filters for A-C Generators, Abner Crumb (graduate student) Worcester Polytechnic Institute.

The Iconoscope, the Eye of Television, S. S. Dufford, Rensselaer Polytechnic Institute.

Single-Phase Railway Motors, W. Malthamer, Jr., Rensselaer Polytechnic Institute.

The Sliding Electrical Contact, D. P. Miles, Rensselaer Polytechnic Institute.

Under the excellent chairmanship of R. W. Kunkle, engineering student, Cornell University, this busy session was conducted with order and dispatch, with the time carefully budgeted between presentations and discussions. Many of the approximately 150 students that attended the session took an active part in the discussion of the papers.

President MacCutcheon, in addressing the group, paid tribute to the student authors for the general excellence of their papers, and the effectiveness with which they were presented, to Student Chairman Kunkle for his efficient handling of the meeting, and to Professor F. N. Tompkins, counselor of the Brown University Student Branch and chairman of the student activities committee for the North Eastern District meeting under whose general supervision the program was arranged and presented. A committee of judges made up of Professors A. R. Powers of Clarkson, E. A. Walker of Tufts, and C. W. Henderson of Syracuse, returned the verdict awarding prizes *for presentation* as follows: first, to Mr. Korman; second, to Messrs. Gay and Hunter; and third, to Mr. Miles. Mr. Williams and Mr. Crumb were awarded honorable mention.

### Conference on Student Activities

At a luncheon business conference held Friday, May 7, a total of 36 persons interested in Student Branch activities gathered together for a discussion of the problems incident to that phase of the Institute's activity in the North Eastern District. This group included student and faculty representatives from 13 of the 16 Student Branches in the North Eastern District, District Secretary R. G. Lorraine of Schenectady, Editor G. R. Henninger of New York, Vice-President A. C. Stevens of Schenectady, National Secretary H. H. Henline of New York, President A. M. MacCutcheon of Cleveland, Professor T. H. Morgan of Worcester Polytechnic Institute, Professor Lynn C. Holmes, counselor-elect of the Branch at Rensselaer Polytechnic Institute, and the following representatives:

**Student Branch Counselors and Alternates**

F. N. Tompkins, Brown University, Providence, R. I.
A. R. Powers, Clarkson College of Technology, Potsdam, N. Y.
E. M. Strong, Cornell University, Ithaca, N. Y.
J. D. Cobine, Harvard University, Cambridge, Mass.
W. H. Bliss, University of Maine, Orono
W. H. Timbie, Massachusetts Institute of Technology, Cambridge
L. W. Hitchcock, University of New Hampshire, Durham
F. M. Sebast, Rensselaer Polytechnic Institute, Troy, N. Y.
C. W. Henderson, Syracuse University, N. Y.
E. A. Walker, Tufts College, Tufts College, Mass.
E. R. McKee, University of Vermont, Burlington
Victor Siegfried, Worcester Polytechnic Institute, Mass.
A. G. Conrad, Yale University, New Haven, Conn.

**Student Branch Chairmen or Alternates**

Gerald Smithson, Brown University, Providence, R. I.
J. F. Frazier, Clarkson College of Technology, Potsdam, N. Y.
F. J. Skinner, Cornell University, Ithaca, N. Y.
L. P. Winsor, Harvard University, Cambridge, Mass.
H. O. Saunders, Massachusetts Institute of Technology, Cambridge
H. C. Kenneson, University of Maine, Orono
R. W. Tolles, University of New Hampshire, Durham
J. S. Dufford, Rensselaer Polytechnic Institute, Troy, N. Y.
F. C. Tuck, Syracuse University, N. Y.
F. A. Spindell, Tufts College, Mass.
J. R. Tozer, Jr., University of Vermont, Burlington
R. P. Day, Worcester Polytechnic Institute, Mass.
R. D. Scott, Yale University, New Haven, Conn.

Among the various items of business discussed, principal attention was given to: (*a*) the desirability of providing more and better housing arrangements and entertainment features for students attending these District student conventions; (*b*) the desirability of divorcing the student conventions from District meetings; (*c*) the question of a proper basis for the competitive grading of student papers.

The weight of student opinion was to the effect that adequate attention already is being given to the provision of facilities for students in connection with District meetings, and that any further efforts in that direction would nullify some of the educational benefits accruing to the students by virtue of having to do a bit of caring for themselves in a strange community, a situa-

**A group of authors who presented papers at the Buffalo meeting**

S. K. Waldorf, Baltimore, Md.; G. A. Powell, Albany, N. Y.; I. W. Gross, New York, N. Y.; J. M. Geiger, Buffalo, N. Y.; Donald Scranton, Buffalo, N. Y.; W. F. Davidson, Brooklyn, N. Y.; W. P. Dobson, Toronto, Can.; R. E. Corey, Syracuse, N. Y.; D. C. Stewart, Buffalo, N. Y.; L. A. Umansky, Schenectady, N. Y.

R. W. Kunkle, chairman Cornell — N. I. Korman Worcester — P. H. Hunter Cornell — D. O. Wood M.I.T. — S. S. Dufford Rensselaer — E. M. Williams Yale — Abner Crumb Worcester — W. Malthaner, Jr. Worcester — D. P. Miles Rensselaer

**A group of student authors who presented papers at the Buffalo meeting**

tion they all expect to face upon graduation. The general consensus of opinion among both students and counselors was to the effect that electrical engineering students do not need to be "spoon fed." Likewise, the suggestion to separate the student conventions from the regular District meeting program was talked down by a wide margin, 2 important facts being stressed by several speakers: first, that many advantages to students from attending such meetings would be lost if the opportunity to attend the general technical sessions and otherwise mingle with the practicing engineers were eliminated; second, that any need or desire for conclaves devoted wholly to student matters could be satisfied by arranging such conclaves without interferring with the joint District student convention and District meeting which was regarded as having been highly successful over a period of years.

Referring to the basis for the competitive grading of technical papers as published on page 492 of the April 1937 issue of ELECTRICAL ENGINEERING, there was a strongly expressed and apparently widely held opinion among Student Branch counselors that the published basis was not satisfactorily applicable to student papers. Two factors were pointed out as being of particular significance in connection with the grading of student papers: first, "the broad interpretation and importance of 'originality' "; second, "the lesser expectancy of 'value' to the profession in student papers and the unimportance of attempting to segregate it into the present 'value in its field,' and 'value to electrical engineering.' " A committee of counselors that has been studying this matter recommended the following basis for grading student papers:

| | |
|---|---|
| Preliminary analysis | 20 per cent |
| Logical presentation | 20 per cent |
| Originality in handling subject | 20 per cent |
| Unity of composition | 20 per cent |
| Value to electrical engineering | 20 per cent |

This report and recommendation was accepted by a vote. Also there was expressed a desire for continued study of grading "in favor of more drastic revision" and Chairman Tompkins was requested to appoint a committee for the purpose.

### ENTERTAINMENT—ATTENDANCE

The principal feature of the entertainment program at the Buffalo meeting was a very nicely arranged dinner held the evening of the second day, and departing from common practice in that it was not a dinner dance. President and Mrs. A. M. MacCutcheon were the guests of honor. Entertainment as well as instruction was afforded through an interesting demonstration lecture "Kodachrome Colored Film," given by L. D. Mannes of the Eastman Kodak Company, Rochester, N. Y., co-inventor of a color photography process in which a single negative comprises 3 successively deposited sensitized films, each sensitive to a different primary color, and each separated from its neighbors by a neutral deposit which enables the complicated developing process to be carried on step-by-step, progressively bringing out the several layers, the composite of which is an accurate color reproduction. The reported attendance was 273.

### DISTRICT EXECUTIVE COMMITTEE MEETS

A luncheon meeting of the North Eastern District executive committee was held Thursday, May 6, during the Buffalo meeting. After routine matters had been disposed of, there was considerable discussion concerning the registration of professional engineers in connection with the discussion of the general topic of "broadening" of Institute activities. Pittsfield, Mass., was selected as the site for the 1938 District meeting.

The meeting was attended by the following delegates:

A. C. Stevens, vice-president, AIEE
R. G. Lorraine, secretary, North Eastern District
F. N. Tompkins, chairman, District Committee on student activities
R. F. Chamberlain, chairman, Ithaca Section
C. L. Dawes, chairman, Boston Section
C. M. Foust, chairman, Schenectady Section
E. M. Hunter, secretary, Schenectady Section
K. B. McEachron, chairman, Pittsfield Section
R. M. Pfalzgraff, chairman, Lynn Section
H. C. Rankin, chairman, Providence Section
J. Leo Scanlon, chairman, Niagara Frontier Section
V. Siegfried, vice-chairman, Worcester Section
B. M. Werly, secretary, Rochester Section

The meeting was attended also by President A. M. MacCutcheon, Chairman W. H. Timbie of the Sections committee, National Secretary H. H. Henline, Editor G. R. Henninger, Chairman V. G. Smith of the Toronto, Ontario, Section, Chairman-Elect Ralph M. Darrin of the Niagara Frontier Section, and B. K. Northrop of the Ithaca Section.

During the dinner meeting, Vice-President A. C. Stevens announced the following winners of District prizes for 1936 technical papers, and made awards accordingly: (1) for the best Student Branch paper, William A. Harry of Cornell, now with the Bell Telephone Laboratories; (2) for first paper prize, Edgar A. Harty (A'22,M'36) in charge of design and manufacture of copper oxide rectifiers for the General Electric Company, Lynn, Mass.; (3) for the best paper prize, E. M. Hunter (A'28, M'36) central station engineering department, General Electric Company, Schenectady, N. Y. Details of these awards are covered in the formal report on paper prizes published elsewhere in this issue.

Another interesting demonstration lecture was delivered the evening of the first day by L. W. W. Morrow (A'13, F'25) general manager of the fiber products division of the Corning Glass Works, Corning, N. Y., on the subject of "Fibrous Glass." This is a new product of amazing characteristics. Although glass in every sense of the word manufactured by a secret process, the fibers look and feel not unlike silk, and lend themselves to the manufacture of all manner of fabrics through the use of regular textile manufacturing machines, in addition to having the inherent characteristics of glass, such as fireproofness and nonabsorbence of liquids. This new product is essentially an alloy, as is glass in any form, and has many properties similar to metallic alloys. A temperature of some 1,200 or 1,400 degrees centigrade is required to melt and mix the constituents preparatory to drawing the fibers. The fibers are about 0.0004 inch in diameter, and from 1.5 to 20 inches long, are heat-resistant, nonabsorbent, and strong (reputedly the equivalent of about a million pounds per square inch in the smaller fibers). It is a product of recent research and already is being used in the manufacture of textiles, insulating and other tapes, insulating pipe coverings, and house insulation, and the future seems wide open with possibilities for application in the manufacture of electrical equipment.

Registration is reported and analyzed in the accompanying tabulation.

**Analysis of Registration at Buffalo Meeting**

| Classification | Location | | | |
|---|---|---|---|---|
| | Buffalo | District 1* | Other Districts | Totals |
| Members | 63 | 80 | 44 | 187 |
| Students | 2 | 71 | 5 | 78 |
| Men guests | 22 | 35 | 11 | 68 |
| Women guests | 8 | 9 | 2 | 19 |
| Totals | 95 | 195 | 62 | 352 |

* Outside of Buffalo.

**Refrigerating and Air Conditioning Machinery Manufacturers Meet.** The Refrigerating Machinery Association met on May 12 and 13, 1937, at Hot Springs, Va., and immediately following, on May 14 and 15, the Air Conditioning Manufacturers' Association held its annual meeting.

# Section and Branch Activities

## Annual Report for 1936-37

THE following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1937. Similar information for 3 preceding fiscal years appeared in ELECTRICAL ENGINEERING for June 1936, pages 752–54; June 1935, pages 674–75; and June 1934, pages 1027–29.

The names of our present members of the Sections committee and the committee on Student Branches, which supervise the 2 important divisions of Institute activities covered by this report, are: Sections—W. H. Timbie, *chairman*, W. M. Dann, Mark Eldredge, O. W. Holden, E. T. Mahood, H. H. Race, I. M. Stein, and, *ex-officio*, the chairmen of all Sections of the Institute. Student Branches—F. Ellis Johnson, *chairman*, Edward Bennett, L. A. Doggett, E. E. Dreese, O. E. Edison, O. W. Eshbach, T. W. Fitzgerald, E. A. Loew, Charles F. Scott, R. W. Sorensen, and, *ex-officio*, all Student Branch counselors.

### SECTION ACTIVITIES

The East Tennessee Section was organized in September and enthusiastically began carrying on a normal amount of activity. This brought the total number of Sections to 62. Three prospective new Sections are being actively discussed.

Practically all the 62 Sections carried on at least normal amounts of activity, and many were unusually active. The total number of meetings reported was 621, or 81 more than the total for the preceding year.

President MacCutcheon visited about 40 Sections prior to April 30, and will visit several others, bringing the total number to about 47. He was enthusiastically welcomed, and his visits contributed much to the success of Section activities.

The outstanding development in Section activities in recent years is the inauguration of special types of meetings designed to meet as fully as possible the desires of the members. Eighteen Sections have adopted plans for holding technical group, technical committee, special technical, or other types of meetings devoted to more highly specialized subjects than those usually presented at regular Section meetings. The types of such activities usually have been chosen after receipt of replies to questionnaires requesting members to express their principal technical interests.

In 3 Sections, Alabama, Montana, and Toronto, local group meetings were held at points in their territories from which few members could attend regular Section meetings.

Table I contains tabular information on the meetings of all Sections and of their technical groups, technical committees, discussion groups, and other subdivisions. Information on many of these special activities has appeared in ELECTRICAL ENGINEERING during the past year. In the following statements, particular attention is given to some of the more recent developments, and especially to those of newer types.

The Toronto Section established a discussion group having as its purpose the development of engineers in the preparation and presentation of 5-minute talks and discussions. Meetings 40 minutes in length were held immediately preceding regular Section meetings and at the same place. Three talks and general discussion constituted the program of each. It is expected that this plan will be continued next year for the purpose mentioned and also to improve the knowledge of the members in economics and human relations in engineering.

The Toronto Section also formed a technical discussion group which met at supper on the evenings of Section meetings, and then held its discussions between 6:05 and 7:45. The general subject was "Control and Protective Practice"; 3 or 4 papers were presented at each meeting.

The Seattle Section sent a questionnaire

**Table I. Section Meetings Held During Year Ending April 30, 1937**

| Section | AIEE Members: August 1935 | AIEE Members: August 1936 | Meetings During Year: Number | Meetings During Year: Average Attendance | Avg. Attendance as Per Cent of Membership, August 1936 |
|---|---|---|---|---|---|
| Akron | 64 | 67 | 8 | 90 | 134 |
| Alabama | 38 | 42 | 7 | 270 | 643 |
| Muscle Shoals power subgroup | | | 3 | 66 | |
| Atlanta | 71 | 72 | 5 | 77 | 107 |
| Baltimore | 167 | 174 | 9 | 169 | 97 |
| Boston | 378 | 386 | 8 | 172 | 45 |
| Central Indiana | 94 | 116 | 5 | 82 | 71 |
| Chicago | 614 | 603 | 7 | 212 | 35 |
| Power group | | | 2 | 96 | |
| Industrial group | | | 5 | 131 | |
| Cincinnati | 143 | 159 | 9 | 284 | 178 |
| Cleveland | 220 | 245 | 8 | 134 | 55 |
| Industrial motors and control group | | | 3 | 60 | |
| Electronics | | | 3 | 32 | |
| Columbus | 62 | 63 | 8 | 44 | 70 |
| Technical lectures | | | 13 | 8 | |
| Connecticut | 225 | 267 | 8 | 123 | 46 |
| Dallas | 87 | 89 | 6 | 48 | 54 |
| Denver | 138 | 132 | 10 | 46 | 35 |
| Technical committee | | | 1 | 55 | |
| Detroit-Ann Arbor | 268 | 320 | 10 | 150 | 47 |
| Special Technical Meeting | | | 1 | 25 | |
| East Tennessee* | | 49 | 8 | 44 | 90 |
| Erie | 48 | 52 | 9 | 74 | 142 |
| Florida | 47 | 60 | 2 | 129 | 215 |
| Fort Wayne | 55 | 64 | 12 | 103 | 161 |
| Houston | 65 | 75 | 9 | 50 | 67 |
| Iowa | 50 | 56 | 8 | 100 | 179 |
| Ithaca | 56 | 54 | 10 | 126 | 233 |
| Kansas City | 134 | 148 | 10 | 152 | 103 |
| Lehigh Valley | 185 | 184 | 8 | 114 | 62 |
| Los Angeles | 385 | 440 | 9 | 102 | 23 |
| Special technical meeting | | | 1 | 65 | |
| Louisville | 56 | 50 | 5 | 60 | 120 |
| Lynn | 99 | 120 | 14 | 373 | 311 |
| Technical lectures | | | 3 | 87 | |
| Madison | 51 | 48 | 4 | 46 | 96 |
| Memphis | 31 | 33 | 10 | 48 | 145 |
| Mexico | 66 | 67 | 5 | 40 | 60 |
| Milwaukee | 173 | 208 | 11 | 177 | 85 |
| Minnesota | 74 | 72 | 9 | 45 | 63 |
| Power committee | | | 4 | 22 | |
| Montana | 34 | 38 | 6 | 70 | 18 |
| Fort Peck group | | | 4 | 17 | |
| Nebraska | 51 | 56 | | | |
| New Orleans | 44 | 50 | 5 | 73 | 146 |
| New York | 2,773 | 3,036 | 4 | 632 | 21 |
| Power group | | | 7 | 276 | |
| Transportation group | | | 3 | 143 | |
| Communication group | | | 4 | 381 | |
| Illumination group | | | 3 | 317 | |
| Niagara Frontier | 197 | 208 | 8 | 137 | 66 |
| North Carolina | 78 | 83 | 2 | 108 | 130 |
| Oklahoma City | 110 | 120 | 7 | 121 | 101 |
| Philadelphia | 517 | 550 | 8 | 118 | 21 |
| System characteristics group | | | 1 | | |
| Pittsburgh | 379 | 411 | 8 | 181 | 44 |
| Pittsfield | 107 | 121 | 10 | 765 | 632 |
| Colloquium series | | | 6 | 29 | |
| Portland | 92 | 110 | 9 | 82 | 75 |
| Illumination committee | | | 2 | | |
| Trans. & Dist. committee | | | 3 | 46 | |
| Electrochem. and Electrometallurgy com. | | | 2 | | |
| Communication committee | | | 2 | 33 | |
| Providence | 85 | 82 | 7 | 112 | 137 |
| Rochester | 71 | 80 | 14 | 125 | 156 |
| Communication group | | | 3 | 18 | |
| Power group | | | 2 | 30 | |
| St. Louis | 182 | 201 | 8 | 111 | 55 |
| San Antonio | 26 | 29 | 7 | 34 | 117 |
| San Francisco | 373 | 401 | 9 | 200 | 50 |
| Special technical meetings | | | 5 | 56 | |
| Saskatchewan | 24 | 25 | 7 | 27 | 108 |
| Schenectady | 353 | 367 | 12 | 219 | 60 |
| Technical discussion meetings | | | 4 | 50 | |
| Junior discussion group | | | 5 | 25 | |
| Seattle | 117 | 146 | 9 | 52 | 36 |
| Transmission & distribution | | | 6 | 28 | |
| Communications | | | 4 | 13 | |
| Electronics & electron tubes | | | 4 | 20 | |
| Power generation | | | 4 | 20 | |
| Sharon | 55 | 62 | 9 | 99 | 160 |
| Technical discussion meetings | | | 2 | 40 | |
| Spokane | 44 | 48 | 7 | 44 | 92 |
| Springfield, Mass. | 65 | 68 | 9 | 60 | 88 |
| Syracuse | 65 | 71 | 4 | 379 | 533 |
| Toledo | 69 | 66 | 11 | 59 | 89 |
| Toronto | 286 | 293 | 13 | 114 | 39 |
| Discussion group | | | 10 | 25 | |
| Technical discussion group | | | 8 | 38 | |
| Hamilton group | | | 2 | 165 | |
| Urbana | 36 | 36 | 6 | 24 | 67 |
| Utah | 39 | 41 | 8 | 49 | 120 |
| Vancouver | 88 | 97 | 10 | 60 | 62 |
| Virginia | 86 | 90 | 2 | 36 | 40 |
| Washington | 229 | 258 | 8 | 144 | 56 |
| Worcester | 62 | 63 | 8 | 94 | 149 |
| Total...62 | 10,881 | 11,822 | | | |

Total number of meetings............. 621
Total attendance..................... 74,950

* Organized September 2, 1936.

**Table II. Courses of Instruction Offered by Sections**

| Section | Subject | Member Fee | Duration | Enrollment |
|---|---|---|---|---|
| Lynn | Electronics | $10.00 | October-December | 21 |
| New York | | | | |
| Power group | Electrical engineering | 10.00 | 20 weeks—September | 53 |
| | | | (Repeated)—January | 45 |
| | Structural planning and design | 10.00 | 20 weeks—September | 170 |
| | | | (Repeated)—January | 200 |
| | Industrial control lectures | 2.00 | 8 weeks | 120 |
| | Public speaking | 15.00 | 16 weeks—September | 17 |
| | | | (Repeated)—January | 15 |
| Communication group | Electronics lectures | 2.00 | 8 weeks | 300 |
| Niagara Frontier | Applied structural design | | October-January | 50 |
| Philadelphia | Electrical theory review | 15.00 | September-May | 23 |
| | Mathematics review | 15.00 | September-May | 25 |
| | Electronics (repeat) | 12.00 | January-May | 27 |
| | Any 2 courses | 25.00 | | |
| Springfield | Electronics | 10.00 | January-May | 30 |
| Vancouver | Electronics and electron tubes | 7.50 | 20 weeks | 27 |

to its members and to the members of the University of Washington Branch, in October 1936, asking whether they would be interested in taking part in technical group meetings devoted to 6 subjects which were named or to other subjects which they were invited to suggest. After a tabulation of the responses, the executive committee decided to organize technical groups covering the 4 subjects in which the greatest interest had been shown: transmission and distribution, power generation, communication, and electronics and electron tubes. Free discussion was encouraged. Attendance was very good, comparable in many cases with that at regular Section meetings.

The Schenectady Section junior discussion group held dinner meetings to which the younger members of the local Sections of several engineering societies were invited. Opportunities were presented for open discussions on technical and general subjects. It also held a technical discussion series of dinner meetings for members of the Sections. Subjects were chosen by use of a postal card interest finder.

The Columbus Section held a series of lectures on technical subjects of special interest to its members.

The Pittsfield Section held a colloquium series for brief presentations by specialists of published papers of interest to electrical engineers and general discussions of them.

The Philadelphia Section arranged near the end of the year for 2 technical discussion groups: one on system characteristics under fault conditions, the other on industrial applications of electricity.

The Rochester Section organized communication and power groups.

The power group of the Chicago Section continued its work with notable success, and an industrial group was formed.

The Cleveland Section continued its industrial motor and control group, and organized an electronics group.

The Denver Section organized a technical committee, and the Detroit-Ann Arbor

**Table III. Section Meetings Held During Last 3 Fiscal Years**

| | Fiscal Year Ending April 30 | | |
|---|---|---|---|
| | 1935 | 1936 | 1937 |
| Number of Sections | 61 | 61 | 62 |
| Number of meetings held | 521 | 540 | 621 |
| Average number of meetings | 8.5 | 8.9 | 10.0 |
| Total attendance | 73,381 | 85,501 | 74,950 |
| Average attendance per meeting | 141 | 158 | 121 |

**Table IV. Branch Meetings Held During Year Ending April 30, 1937**

| Branch | Meetings During Year: Number | Meetings During Year: Average Attendance | Approx. No. of Talks by Students |
|---|---|---|---|
| Akron, University of | 6 | 7 | 7 |
| Alabama Polytechnic Institute | 14 | 34 | 4 |
| Alabama, University of | 19 | 24 | 12 |
| Arizona, University of | 30 | 10 | 15 |
| Arkansas, University of | 20 | 20 | 19 |
| Armour Institute of Technology | 12 | 35 | 2 |
| British Columbia, Univ. of | 8 | 22 | 14 |
| Brooklyn, Polytechnic Inst. of | 8 | 101 | 7 |
| Brown University | 3 | 57 | — |
| Bucknell University | 13 | 23 | 7 |
| California Institute of Technology | 14 | 25 | 1 |
| California, University of | 22 | 62 | 15 |
| Carnegie Institute of Tech | 23 | 35 | 48 |
| Case School of Applied Science | 28 | 54 | 56 |
| Catholic University of America | 1 | 9 | — |
| Cincinnati, University of | 8 | 64 | 3 |
| Clarkson College of Technology | 10 | 20 | — |
| Clemson Agricultural College | 10 | 41 | 13 |
| Colorado State Agri. College | 6 | 7 | 4 |
| Colorado, University of | 11 | 46 | — |
| Columbia University* | 9 | 25 | 3 |
| Cooper Union | | | |
| Day division | 7 | 24 | 5 |
| Evening division | 7 | 17 | 5 |
| Cornell University | 6 | 25 | 4 |
| Denver, University of | 13 | 22 | 2 |
| Detroit, University of | 3 | 80 | — |
| Drexel Institute | 15 | 19 | 10 |
| Duke University | 16 | 45 | 30 |
| Florida, University of | 12 | 28 | 3 |
| George Washington University | 8 | 27 | 10 |
| Georgia School of Technology | 7 | 37 | 4 |
| Harvard University | 3 | 30 | 1 |
| Idaho, University of | 8 | 35 | 7 |
| Illinois, University of | 12 | 75 | 6 |
| Iowa State College | 16 | 60 | 4 |
| Iowa, University of | 26 | 35 | 26 |
| Johns Hopkins University | 22 | 25 | 23 |
| Kansas State College | 15 | 95 | 20 |
| Kansas, University of | 9 | 40 | 10 |
| Kentucky, University of | 24 | 50 | 6 |
| Lafayette College | 6 | 19 | 15 |
| Lehigh University | 7 | 84 | 4 |
| Lewis Institute | 9 | 53 | — |
| Louisiana State University | 13 | 24 | 6 |
| Louisville, University of | 9 | 10 | 4 |
| Maine, University of | 3 | 29 | — |
| Marquette University | 11 | 57 | — |
| Maryland, University of | 10 | 43 | 10 |
| Massachusetts Inst. of Tech | 8 | 84 | 6 |
| Michigan College of Min. & Tech | 9 | 43 | 3 |
| Michigan State College | 10 | 30 | 4 |
| Michigan, University of | 10 | 23 | 2 |
| Milwaukee School of Engineering | 10 | 40 | 1 |
| Minnesota, University of | 7 | 55 | 5 |
| Mississippi State College | 15 | 15 | 10 |
| Missouri School of Mines & Met | 9 | 49 | 5 |
| Missouri, University of | 10 | 48 | 6 |
| Montana State College | 26 | 23 | 69 |
| Nebraska, University of | 14 | 29 | 6 |
| Nevada, University of | 8 | 20 | — |
| Newark College of Engineering | 4 | 35 | 6 |
| New Hampshire, University of | 21 | 20 | 28 |
| New Mexico, University of | 10 | 14 | 5 |
| New York, College of the City of | | | |
| Day division | 32 | 25 | 14 |
| Evening division | 14 | 11 | 3 |
| New York University | | | |
| Day division | 15 | 30 | 35 |
| Evening division | — | — | — |
| North Carolina State College | 12 | 33 | 23 |
| North Carolina, University of | 12 | 18 | 10 |
| North Dakota State College | 6 | 15 | 3 |
| North Dakota, University of | 14 | 14 | 9 |
| Northeastern University | 6 | 40 | — |
| Notre Dame, University of | 8 | 26 | 10 |
| Ohio Northern University | 12 | 14 | 6 |
| Ohio State University | 7 | 36 | 1 |
| Ohio University | 9 | 30 | 2 |
| Oklahoma A. & M. College | 13 | 42 | 6 |
| Oklahoma, University of | 6 | 29 | 2 |
| Oregon State College | 6 | 47 | 3 |
| Pennsylvania State College | 11 | 45 | 11 |
| Pennsylvania, University of | 5 | 21 | 6 |
| Pittsburgh, University of | 23 | 63 | 11 |
| Porto Rico, University of | — | — | — |
| Pratt Institute | 10 | 68 | 1 |
| Princeton University | 2 | 15 | — |
| Purdue University | 12 | 107 | — |
| Rensselaer Polytechnic Institute | 7 | 51 | 18 |
| Rhode Island State College | 6 | 28 | — |
| Rice Institute | 6 | 23 | 2 |
| Rose Polytechnic Institute | 7 | 33 | 12 |
| Rutgers University | 10 | 13 | 5 |
| Santa Clara, University of | 21 | 39 | 2 |
| South Carolina, University of | 8 | 8 | — |
| South Dakota State College | 13 | 17 | 17 |
| South Dakota State School of Mines | 10 | 14 | 1 |
| Southern California, Univ. of | 11 | 25 | 2 |
| Southern Methodist University | 7 | 23 | 4 |
| Stanford University | 11 | 33 | 3 |
| Stevens Institute of Technology | 8 | 82 | — |
| Swarthmore College | 8 | 22 | 15 |
| Syracuse University | 31 | 9 | 40 |
| Tennessee, University of | 9 | 33 | 1 |
| Texas A. & M. College | 8 | 40 | 5 |
| Texas Technological College | 12 | 17 | 17 |
| Texas, University of | 17 | 33 | 7 |
| Tufts College | 8 | 35 | 3 |
| Tulane University* | 4 | 20 | 1 |
| Union College | 4 | 20 | — |
| Utah, University of | 10 | 29 | 2 |
| Vermont, University of | 6 | 29 | — |
| Villanova College | 12 | 13 | 12 |
| Virginia Military Institute | 22 | 34 | 26 |
| Virginia Polytechnic Institute | 25 | 35 | 39 |
| Virginia, University of | 5 | 20 | 5 |
| Washington, State College of | 12 | 23 | 5 |
| Washington, University of | 12 | 36 | 11 |
| Washington University | 13 | 24 | — |
| West Virginia University | 17 | 27 | 101 |
| Wisconsin, University of | 6 | 66 | 1 |
| Worcester Polytechnic Institute | 4 | 42 | 5 |
| Wyoming, University of | 9 | 11 | 8 |
| Yale University | 6 | 23 | 3 |
| Total....119 | | | 1,130 |

Total number of meetings............. 1,363
Total attendance.................... 46,121

* Authorized by Board of Directors January 26, 1937.

## Table V. Branch Meetings Held During Last 3 Fiscal Years

| | Fiscal Year Ending April 30 | | |
|---|---|---|---|
| | 1935 | 1936 | 1937 |
| Number of Branches | 117 | 118 | 119 |
| Number of meetings held | 986 | 1,045 | 1,363 |
| Average number of meetings | 8.4 | 8.9 | 11.5 |
| Total attendance | 36,629 | 45,304 | 46,121 |
| Average attendance per meeting | 37 | 43 | 33.8 |
| Number of student talks | 708 | 772 | 1,130 |

## Table VI. Conferences on Student Activities

| District or Section | Location | Date |
|---|---|---|
| 7 | University of Arkansas, Fayetteville | 5/2/36 |
| 1 | New Haven, Conn. (North Eastern District meeting) | 5/8/36 |
| 8 & 9 | Pasadena, Calif. (Summer convention) | 6/23/36 |
| 7 | Dallas, Texas (South West District mtg.) | 10/27/36 |
| 2 | Ohio State University, Columbus | 11/13-14/36 |
| Pittsburgh Section | Pittsburgh, Pa | 1/12/37 |
| 4 | Alabama Polytechnic Institute, Auburn | 4/2/37 |
| 6 | South Dakota State College, Brookings | 4/23/37 |

and Los Angeles Sections adopted plans for special technical meetings. The Lynn Section had several technical lectures. The Minnesota Section formed a power committee in the spring of 1936. The communication, illumination, power, and transportation groups of the New York Section continued their highly effective activities. The Portland Section communication, electrochemistry and electrometallurgy, illumination, and transmission and distribution groups were continued with excellent results. The San Francisco and Sharon Sections continued their special technical meetings.

The Lynn Section held a technical paper competition on April 6, 1937, offering 3 prizes of $15, $10, and $5, with the decisions based 1/3 on written papers, 1/3 on oral presentation, and 1/3 on ballot by the audience. The Springfield Section announced, in March 1937, a prize paper contest, opening at that time and closing on September 13, 1937, the subject being "Ways and Means to Improve the Springfield Section of the AIEE." The prizes are $25 and $10. Several Sections continued the prizes offered annually in the past.

The Pittsfield and Schenectady Sections held their annual competition in 2 joint meetings, one in each city, with 3 speakers representing each Section at each of the meetings. Prizes of $15 and $10 were awarded at each meeting.

The Schenectady Section held its fourth annual competition among men in the General Electric Company testing department, having 6 speakers selected from the original group of 21. Prizes of $10 and $5 were presented.

Sections that have been sponsoring student conventions and holding joint meetings with neighboring Branches continued the arrangements. The Baltimore Section sponsored a convention of the Student Branches in the eastern part of District 2 on April 19, 1937.

Table II contains information regarding courses of instruction offered by 6 Sections. In some cases the courses are open to nonmembers at higher fees. The fees were established at amounts that would meet the expenses involved. The Philadelphia Section reported that its courses have been valuable in building up interest in the Section, and have been responsible for obtaining a considerable number of new members and reinstatements. Other Sections reported keen and well-sustained interest in the courses.

Table III contains numerical information on Section meetings held during the past 3 years.

### Branch Activities

Two new Student Branches were organized during the year, one at Columbia University, New York, N. Y., on February 19, and the other at Tulane University, New Orleans, La., on March 1; both have been very active.

Nearly all Branches carried on a normal amount of activity, 87 having held 8 or more meetings each, and only 6 having held fewer than 4 meetings. Comprehensive information on many phases of Branch activities appears in Tables III to VIII, inclusive.

The total number of Branch meetings held during the year, as reported to headquarters, was 1,363, by far the largest number ever held in a fiscal year. The largest previous number was 1,137 for the year 1930–31, and the number for 1935–36 was 1,045.

The number of talks by students was also the largest number ever reported—1,130, as compared with 772 for the preceding year, and the largest previous number, 1,085, for the year 1930–31. However many Branches had few or no student talks, and this phase of the activities should receive more attention in the future.

Students have continued to show very

## Table VII. Student Conventions

| Sponsored by District or Section | Location | Date | No. of Student Papers |
|---|---|---|---|
| 7 | University of Arkansas, Fayetteville | 5/1/36 | 13 |
| 1 | New Haven, Conn. (North Eastern District mtg.) | 5/8/36 | 9 |
| 8 & 9 | Pasadena, Calif. (Summer convention) | 6/24–26/36 | 10 |
| 7 | Dallas, Texas (South West District mtg.) | 10/27/36 | 9 |
| Pittsburgh Section | Pittsburgh, Pa | 1/12/37 | 6 |
| 4 | Alabama Polytechnic Institute, Auburn, Ala | 4/2/37 | 6 |
| Baltimore Section | Johns Hopkins University, Baltimore, Md. | 4/19/37 | 4 |
| New York Section | New York University, New York, N. Y. | 4/28/37 | 5 |

## Table VIII. Section or Joint Section and Branch Meetings With Active Student Participation

| Sections | Schools | Date | Student Talks | Attendance |
|---|---|---|---|---|
| Minnesota | University of Minnesota | 5/13/36 | 4 | 54 |
| New Orleans | Louisiana State University | 5/15/36 | 2 | 105 |
| St. Louis | Missouri School of Mines and Metallurgy, University of Missouri, Washington University | 5/15/36 | 6 | 93 |
| Portland | Oregon State College | 5/16/36 | 3 | 60 |
| Cincinnati | University of Cincinnati | 5/19/36 | 4 | 100 |
| Utah | University of Utah | 5/25/36 | 4 | 35 |
| Kansas City | Kansas State College, University of Kansas | 12/3/36 | 4 | 100 |
| Vancouver | University of British Columbia | 3/1/37 | 4 | 52 |
| Dallas | Southern Methodist University | 3/1/37 | 3 | 70 |
| Houston | A. & M. College of Texas, Rice Institute | 3/11/37 | 2 | 60 |
| Atlanta | Georgia School of Technology | 3/15/37 | 4 | 40 |
| East Tennessee | University of Tennessee | 3/16/37 | 1 | 30 |
| Florida | University of Florida | 3/19/37 | 1 | 177 |
| Worcester | Worcester Polytechnic Inst | 4/6/37 | 5 | 51 |
| Seattle | University of Washington | 4/12/37 | 2 | 57 |
| Washington | University of Maryland, George Washington University, Catholic University of America | 4/13/37 | 3 | 140 |
| Los Angeles | University of Southern Calif. Calif. Inst. of Technology | 4/13/37 | 5 | 203 |
| Cleveland | Case School of Applied Science | 4/15/37 | 2 | 117 |
| Minnesota | University of Minnesota | 4/21/37 | 4 | 55 |
| San Francisco | University of California, University of Santa Clara, Stanford University | 4/23/37 | 3 | 152 |
| Spokane | University of Idaho, State College of Washington | 4/30/37 | 2 | 108 |
| Totals—20 Sections, 30 Branches | | | 68 | 1,859 |

keen interest in opportunities to take part in joint Section and Branch meetings and in student conventions. Details regarding such meetings appear in tables VII and VIII.

Students presented 9 papers in one session of the North Eastern District meeting in New Haven, Conn., May 6–9, 1936; 10 papers in 2 sessions of the combined summer and Pacific Coast convention in Pasadena, Calif., June 22–26, 1936; and 9 papers in 2 sessions of the South West District meeting in Dallas, Texas, October 26–28, 1936. They have keenly appreciated these opportunities, and the quality of material and the presentations has inspired numerous favorable comments by Institute members.

About 54% (674) of the Enrolled Students whose terms expired on April 30, 1937 (1,253) applied for admission as Associates, this being the highest percentage during the past several years.

## Engineers' Club Organized at Fort Wayne, Ind.

To provide a medium "for closer co-operation in the engineering profession" in Fort Wayne, Ind., the Fort Wayne Engineers' Club has been organized. Many members of the AIEE Fort Wayne Section have played important parts in formulating the organization plans according to Section Chairman D. H. Hanson who supplied the information for this news item. Although its organization meeting was held in January of this year, the club already has some 350 members representing all branches of the profession and all industries and utilities in the Fort Wayne area.

The primary objects of the club are: "(1) The advancement of the arts and sciences connected with engineering by the presentation and discussion of subjects, and by the participation in matters of interest to the engineering profession; (2) to advance the interest of individual members and to enhance the prestige of the profession within the community; and (3) to promote closer union and co-operation among the members by professional and social intercourse." Civic co-operation is said to be one of its chief purposes.

As temporary officers, the following have been serving:

**President:** H. M. Witherow (A'28, M'36) electrical engineer, General Electric Company, past-chairman (1935–36) of the Fort Wayne Section.

**Vice-President:** W. M. Carroll, mechanical engineer, S. F. Bowser Company.

**Secretary:** P. H. Daily, chemical engineer, International Harvester Company.

**Treasurer:** Otto Gumpper, civil engineer, City of Fort Wayne.

**Temporary Directors:** J. I. Cornell, radio engineer, Magnavox Company; M. H. Merritt, chemical engineer, Kopper's Construction Company; J. Kuttler, automatic engineer, International Harvester Company; E. W. E. Kamm, engineer and patent attorney, S. F. Bowser Company; L. D. Nordstrum (A'04, M'13) electrical engineer, General Electric Company (Section chairman 1914–15); and John McKay, civil engineer, Indiana Service Company.

Regular election will take place at the May meeting of the club.

## Engineering Society Room Constructed at Brown University

TO MEET the need of a social room for engineering students at Brown University, Providence, R. I., a small classroom was remodeled in such manner as to make it an attractive meeting and lounging place. This room, located in the engineering building, is the headquarters of the student engineering societies, and as such forms the natural social center for all engineering students at the university. The following description of the project was supplied by Professor Frederick N. Tompkins, counselor of the AIEE Brown University Branch:

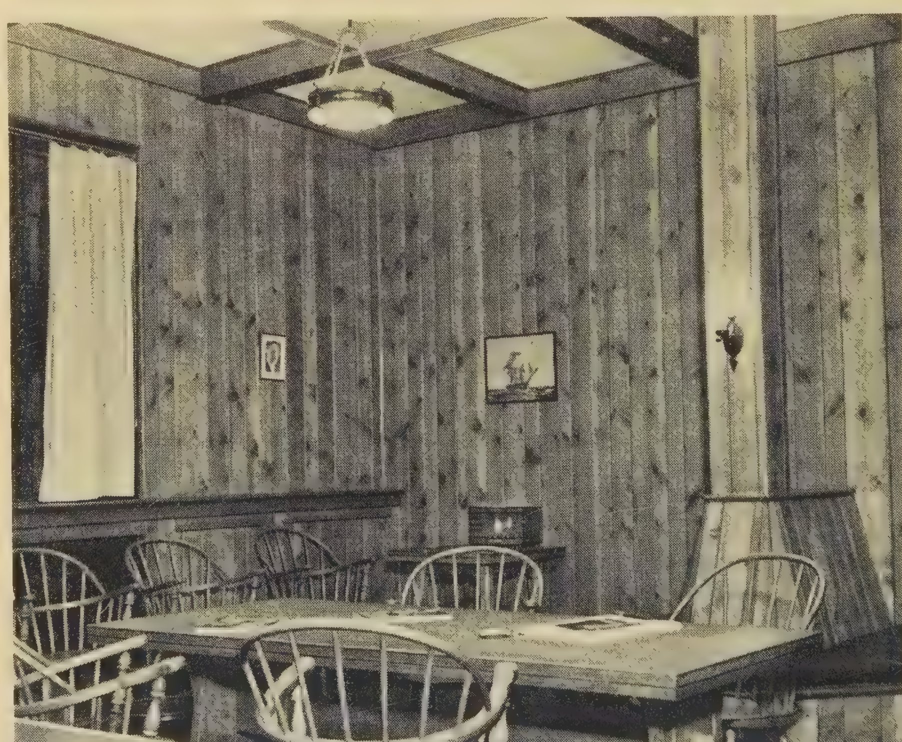
The engineering society organization, as operating at Brown, closely follows that of the Providence Engineering Society. The parent society is the Brown Engineering Society, to which all engineering students are eligible and which serves as a co-ordinating society for the branches of the AIEE, ASME, and ASCE. Practically all the juniors and seniors join one of the branches of the national societies while the freshmen and sophomores seldom do so. Thus, since members of the branches are automatically members of the Brown Engineering Society, membership adapted to all students is provided. Joint meetings are almost always held, small meetings taking place in the society room, larger gatherings in one of the class rooms; and several times each year an evening meeting, including dinner, is held at the University Camp, which is in the country within easy motoring distance of Providence.

As the money for this project was limited, student help was used in the construction under the guidance of members of the staff. An old colonial design was decided upon, and since the room was originally part of a laboratory with a very high ceiling and walls of whitefaced brick, a total reconstruction was necessary. A new beamed and paneled ceiling was hung from the orginal. The panels, which are of Celotex, lift out since the piping and wiring above may need servicing at some time. The walls were sheathed with knotty pine laid vertically, boxes and grills being built around the existing heating coils on two walls. The windows originally were not built to be opened, swinging transoms being provided at the top for ventilation. As the new ceiling was dropped below these, it was necessary to rebuild the windows to the casement type and they were fitted with attractive drapes.

A lally column support for the floor above was boxed in and a leather-covered seat built around its base, thus removing what otherwise would have been an eyesore and detriment to the appearance of the room. The walls were stained with a mixture of oak and walnut stain and finished with a hand-rubbed wax finish. The door did not fit the architecture of the room, so that it was sheathed to correspond and fitted with hand-made antique latches.

Special hand-made ceiling lighting units and antique-type wall brackets were made by a member of the staff who makes a hobby of constructing such material. The question of suitable furniture then arose; it was decided to buy Windsor chairs, but to make the other pieces in so far as possible. Suitable reading and study tables were designed and built, as was a ping-pong table.

A suitable floor covering for the concrete



A view of the engineering society room at Brown University

floor being beyond the budget possibilities at the time, the floor was filled and painted to serve until some future date when a linoleum covering could be purchased.

This room represents one of the finest investments ever made from the standpoint of student morale and usefulness. It is in use nearly all the time and is of particular help to freshmen and sophomores who, since they do not have much work in the laboratories of the engineering division, are apt to feel a lack of contact with their fellow students, particularly with upper classmen.

## Telephone Building for 1939 World's Fair

The American Telephone & Telegraph Company, through its president, Walter S. Gifford (A'16), has contracted with the New York World's Fair Corporation for a building site of more than 3 acres for an exhibit at the fair in 1939. "We plan to erect an imposing structure on the site allocated to us," Mr. Gifford said. "Inspired by the theme of the fair ('building the world of tomorrow'), we intend to construct a building in which we shall give exhibitions of the fascinating forces underlying modern electrical communications. . . . The fair will give our industry the opportunity to tell our story to millions of visitors, and when the fair opens its gates I am sure that the roster of industrial America will be there blazing the trail to a better tomorrow."

The agreement is the first exhibit contract into which the fair corporation has entered; an area of about 75 acres is available for private buildings and is expected to be allocated to exhibitors by similar contracts. Other exhibit space will be available in buildings to be erected by the corporation. The cornerstone of the $900,000 administration building, the first to be erected on the site of the fair at Flushing Meadow in the borough of Queens, was laid April 27, 1937.

## NEMA Welding Section Aids AWS Expansion

The electric welding section of the National Electrical Manufacturers Association, recognizing the important functions of the American Welding Society as a technical spokesman for the welding industry, voted at its January 1937 meeting to furnish financial support to the extent of $10,000 for the expansion program which the AWS recently proposed. A matter of immediate importance is the co-ordination of tests of men, machines, and filler metal, so as to relieve some of the unnecessary burden which a great duplication of test requirements has brought about.

At the March meeting of the NEMA welding section a co-ordinating committee was appointed to work with the management committee of the AWS and to make the fund available as it is required for support of the new activities.

# American Engineering Council

## Report of Patents Committee as Adopted by AEC Assembly

A REPORT of the patents committee of American Engineering Council for the year 1936, as adopted by the assembly of AEC at its annual meeting held January 15, 1937, is presented herewith. In approving the report, the assembly left to action of its executive committee the matter of a budget for financing further studies subject. The personnel of the AEC patents committee for 1936 was: R. S. McBride, *chairman;* David Beecroft, J. H. Critchett, William Grosvenor, F. B. Jewitt (A'03, F'12, past-president) and Warner Seely. Full text of the report follows:

The committee on patents during 1936 considered the 2 major problems assigned to it by action of the assembly in January 1936, and has given brief attention to various legislative hearings and proposed Federal enactments. By correspondence and conference the committee has formulated certain recommendations which it suggests as a basis for action of the staff of the Council during the coming legislative session. It also recommends a somewhat modified plan for future work of the committee.

A number of bills were introduced in the last session of Congress and Congressional hearings held with a view to determining what Congress might do to regulate pooling or cross-licensing of patents. Additional proposals of legislation are contemplated in the next session of Congress. Exploration of this field leads the committee to renew the recommendations of last year and to suggest the adoption of the following resolution by the assembly:

1. American Engineering Council opposes enactment of any forms of legislation thus far introduced into Congress to limit or to regulate pooling or cross-licensing of patents.

The committee feels that the public interest has been much more served than harmed by patent pools and by cross-licensing. Such evils as may have been experienced would not have been corrected by any of the proposed forms of legislation. The committee feels that administration of present laws, including proper and reasonable application of antitrust legislation, would suffice to correct those types of evils of pooling which have been disclosed or charged as bad practice.

Further investigation of this important subject is necessary. It will require considerable work, first in the gathering of information as to past experience of successful pools and cross-licensing plans. The committee believes that such study should be made the major activity of the committee on patents during 1937, and recommends the following resolution:

2. American Engineering Council should provide as a part of the 1937 budget a small allotment of funds in order that specialists and clerical assistance can be secured to make a survey of past experience as the basis of a further study by the patents committee on the subject of pooling and cross-licensing of patents.

At its last annual meeting the assembly of the American Engineering Council expressed its support for the idea of the single Court of Patent Appeals. A definite bill providing for such a court was introduced in the last Congress. Such bill will be reintroduced, probably in several modified forms. The committee believes that Council should give support to the general idea, with such limitations as should be suggested in order to secure the highest standard of technical proficiency in the selection of judges, by the following resolution:

3. American Engineering Council reiterates its approval of the proposed single Court of Patent Appeals to review decisions of the lower courts as applied to facts presented to the lower courts but not for introduction of new evidence. It looks with favor upon the idea of having the judges named to such court selected by the President only after careful review of their special and technical competence with the advice of the engineering and scientific societies as well as advice of the patent bar and the legal profession.

Scientific advisers to the courts have been recommended by a number of agencies, but not all with the same purpose. Most often quoted is the suggestion of a special patents committee of the Science Advisory Board. That committee recommended that scientific advisers be made available to aid *trial* court justices. In this conclusion the committee agrees. The patents committee looks with some favor on such an idea if a suitable method of selecting advisers free from preconceived opinions were fixed and if a sufficiently diversified list of skilled scientific and engineering talent were made available. However, the committee has doubted the wisdom of having such scientific advisers named permanently as a part of a new single Court of Patent Appeals. It feels that the idea of naming 3 such advisers who would serve for all classes of cases would not afford such highly skilled aid in all divisions of science and technology as courts really require. Furthermore, the committee gravely questions whether an appellate court could properly utilize scientific advisers under circumstances that would deny to the litigants all right of examination or cross-examination of such witnesses as to their experience, disinterestedness, reasons for their recommendations, and factual basis for their opinions. The committee recommends the following resolution:

4. American Engineering Council recommends that no provision be made for the naming of scientific advisers to the proposed Court of Patent Appeals.

A wide variety of legislative proposals were before the last Congress intending limitation of life of patents or restriction on freedom of use of patents by owners. Among the varied subjects of legislation were the following: (*a*) taxation during nonuse, and at increasing rates; (*b*) compulsory working; (*c*) compulsory licensing; (*d*) prompt (3-year) final action in the Patent Office;

(*e*) publicity in the Patent Office 3 years from the date of filing; (*f*) expiration of patents 20 years from date of filing; (*g*) free Government use of patents and freedom of Government infringement in times of emergency; (*h*) provision for Government employees patents, with or without free public use; (*i*) validation of patents 5 years after issue, if uncontested.

The committee on patents is unanimously opposed to all these legislative proposals under present circumstances. It believes Council should take some formal action regarding these matters on the following lines:

5. American Engineering Council opposes all the various types of proposals which would restrict the freedom of owners of patents to use them constructively under present laws. It opposes them as not necessary for the public welfare, and prospectively objectionable both from the standpoint of the inventor and the public need for stimulation of progress by inventions. It regards such offenses as are now charged against the patent system as the result of defects in administration of present laws and not as evidence of the need for more legislation.

The committee believes that every effort should be made by industry as well as by the engineering profession to increase the presumption of validity of patents as issued. It feels that engineers generally should assist patent examiners whenever possible to keep abreast of the arts with respect to which they are examining patent applications. The committee has not found any legislation, proposed to date, sufficiently constructive to feel that it deserves support of the American Engineering Council. It does, however, hope that some means may be developed for increasing the standards of competence and experience of the staff of examiners.

Most promising of the proposals for this purpose thus far presented appears to be the suggestion that the number of higher rank and better paid examiners be increased, if necessary at the expense of the number of junior examiners engaged. By this change it is hoped that the more competent and efficient members of the examiner's staff may be advanced in salary and positions more rapidly. It is hoped that there would then be less tendency for the better members of the examiner's staff to resign from the Patent Office early in their career because of unwarranted delay before promotion, such as now often experienced.

The committee does not believe that this matter requires formal action but does suggest that the membership of the engineering profession can well give encouragement to this or any other means found practical for advancing the standards and increasing the technical knowledge of the Patent Office staff.

# Standards

## Railway Motors

A complete revision of AIEE Standard No. 11, "Railway Motors" has been completed by a sectional committee working under the rules of procedure of the American Standards Association and the sponsorship of the Institute. The new American standard is now available in pamphlet form; it is known as No. 11 "Railway Motors and Other Rotating Electrical Machinery for Rail Cars and Locomotives," the new title being indicative of the increased scope of the standard.

A detailed description of the changes that have taken place was covered in an article published in ELECTRICAL ENGINEERING, March 1936, pages 312–13 Copies of the standard are available at 50 cents each with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y

## Wires and Cables

In the standards for wires and cables 8 new specifications have been added, 5 of these representing entirely new developments and 3 being extensive revisions of former standards. All have the status of American Standard or Tentative Standard. A listing of the 8 follows:

*Nos. C8.5, C8.6, C8.7* (published as one pamphlet superseding former AIEE Nos. 69, 70, and 71) Cotton Covered, Silk Covered, and Enameled Round Copper Magnet Wire, respectively. Price 30 cents per copy with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y.

*C8.11 Code Rubber Insulation for Wire and Cable for General Purposes* is based on the requirements for the rubber insulation in the Underwriters' Laboratories' Standard for Code Wire. It is in agreement with the 1936 edition of that standard. Price 20 cents each with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y.

*C8.12 Cotton Braid for Insulated Wire and Cable for General Purposes.* These specifications cover braids as applied to rubber and varnished cloth insulated wires and cables. They do not cover "fancy" or special braids or braids for fixture wire or weather resisting wire and cable. Three classes of braids are covered, namely: heavy, for outdoor or rough service; standard, for indoor or protected service; and code, for installation under the National Electric Code. Price 20 cents each with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y.

*C8.16 Tree Wire Coverings.* Tree wire is a cable having a solid or stranded conductor insulated with a material such as a rubber compound and having a weather- and abrasion-resistant covering. These specifications provide that the coverings shall be of such quality and characteristics that they will not substantially deteriorate with age and proper usage except for a minimum amount of wear due to rubbing against the branches of trees. Price 20 cents each with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y.

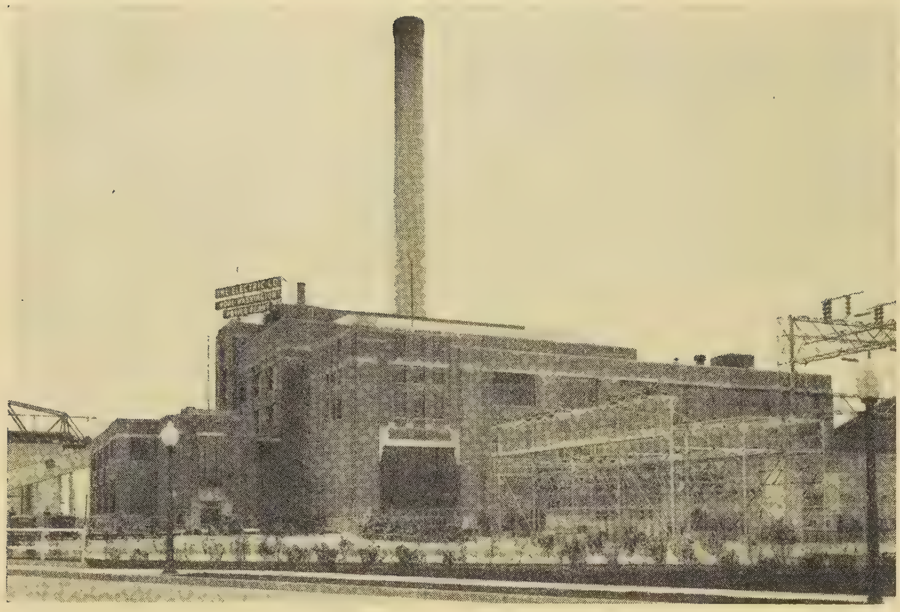
*C8.17 Class OA 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes.* This new standard corresponds to the insulation requirements in ASTM Standard *A*27-55*T* entitled "Insulated Wire and Cable: Class *OA* 30 Per Cent, Hevea Rubber Compound." The clauses with respect to thickness, chemical requirements, and electrical requirements are identical with those for Class *A* 30 Per Cent Compound (*C*8.4—former AIEE No. 63), but the tensile strength and elongation requirements are somewhat higher. Also, there are 2 additional tests not in the class *A* standard: namely, moisture absorption and accelerated aging. Price 20 cents each with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y.

*C8.18 Weather Resistant Wire and Cable URC Type.* These specifications cover weather-resistant (weatherproof) wire and cable, the conductors, the materials used for the fibrous coverings, and the saturating and finishing compounds. They are a further development of specifications originally proposed to the industry by the Utilities Research Commission, Inc. Price 20 cents each with 50 per cent discount to members on single copies. Address AIEE, 33 West 39th Street, New York, N. Y.

**Indicating Electrical Measuring Instruments and Instrument Transformers.** This new publication issued by the National Electrical Manufacturers Association contains the material, revised and augmented that was last published in the NEMA apparatus standards. Of particular interest are the new sections devoted to standard dimensions of indicating instruments and the accuracy limits of current and potential transformers. Price 60 cents each. Address National Electrical Manufacturers Association, 155 East 44th St., New York, N. Y.

**Household Electric Refrigerator Standards.** This pamphlet published by the National Electrical Manufacturers Association covers household electric refrigerators and includes such material as the standard method of computing gross volume and food-shelf area, and also the test code for conducting and reporting such tests as "no load" and "ice making." Price 40 cents each. Address National Electrical Manufacturers Association, 155 East 44th Street, New York, N. Y.

**Test Code on Apparatus Noise Measurement.** The standards committee on April 30 authorized the publication of a "Proposed Test Code for Apparatus Noise Measurement." This code has been prepared under the auspices of the subcommittee on sound of the AIEE standards committee, P. L. Alger, chairman. This test code is intended for use as a guide in the measurement of sound levels and the investigation of the various elements that contribute to the total noise produced. It is an aid to the establishment of reasonably uniform methods of conducting and reporting sound-level tests, so that results will be of value for record and will be comparable with tests made at other times and places. As soon as it is possible to complete the work of publication, notice of availability of the code will be made.



**Port Washington plant of the Milwaukee (Wis.) Electric Railway and Light Company, which may be visited by those attending the Institute's 1937 Summer Convention. For the first 10 months of operation, the average fuel consumption was 11,094 Btu per kilowatt-hour of station output**

# Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy, to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

## Heaviside Calculus and Carson's Integral

*To the Editor:*

The Heaviside operational calculus is finding increasingly widespread application. Accordingly, any device to shorten the work involved in its use would appear of value. In the present note is described a simplification which was found by the writer to greatly facilitate his own computations.

The Heaviside calculus has as its fundamental problem[1] the determination of what is known, in electrical theory, as the "indicial admittance" of a linear physical system. This is simply the response of the system, initially in equilibrium, to a unit disturbance suddenly applied at time zero and maintained constant thereafter. In dynamics, the indicial admittance might correspond to the velocity of a system resulting from a suddenly imparted unit acceleration. In electricity, it is usually the current resulting from a suddenly applied electromotive force of unit magnitude.

Having determined the indicial admittance, the characteristics of a system are then completely determined mathematically, except for a single integration.[1] Adopting electrical terminology, we have the following equation for the current as a function of time, $t$:

$$I(t) = E(0)A(t) + \int_0^t A(t-\tau)\frac{dE(\tau)}{d\tau}\,d\tau$$

where $I$, $E$, and $A$ represent, respectively, current, electromotive force, and indicial admittance, and $\tau$ is the time variable of integration. In other words, knowing the indicial admittance of a circuit, the response of the circuit at any time, $t$, to an arbitrarily varying electromotive force can be determined (at least formally) by application of the above integral. The integral was independently derived by J. R. Carson, but has long been known in dynamics as Duhamel's integral.

The writer had occasion to use the operational calculus in problems involving fairly arbitrary disturbances. The determination of the unit response of "indicial admittance" was a routine application of the Heaviside expansion formula. (This will not be treated here but can be found in all works on the principles of operational calculus.) However, attempts to apply this in the Carson integral, as given above, proved tedious. Graphical solution was no more economical of time, although it must be employed in some form when the disturbance is given by an arbitrary curve. The writer then noticed that the integral could be made considerably less complex. The step taken was extremely simple and obvious, but does not appear to have been made heretofore. By cancelling the $d\tau$'s, and correspondingly changing the limits of integration, the integral becomes

$$I(t) = \int_0^{E(t)} A(t-\tau)\,dE(\tau)$$

(The term $E(0)A(t)$ is now included by the lower limits of integration.)

To evaluate this graphically it is only necessary to plot $A(t - \tau)$ against corre-

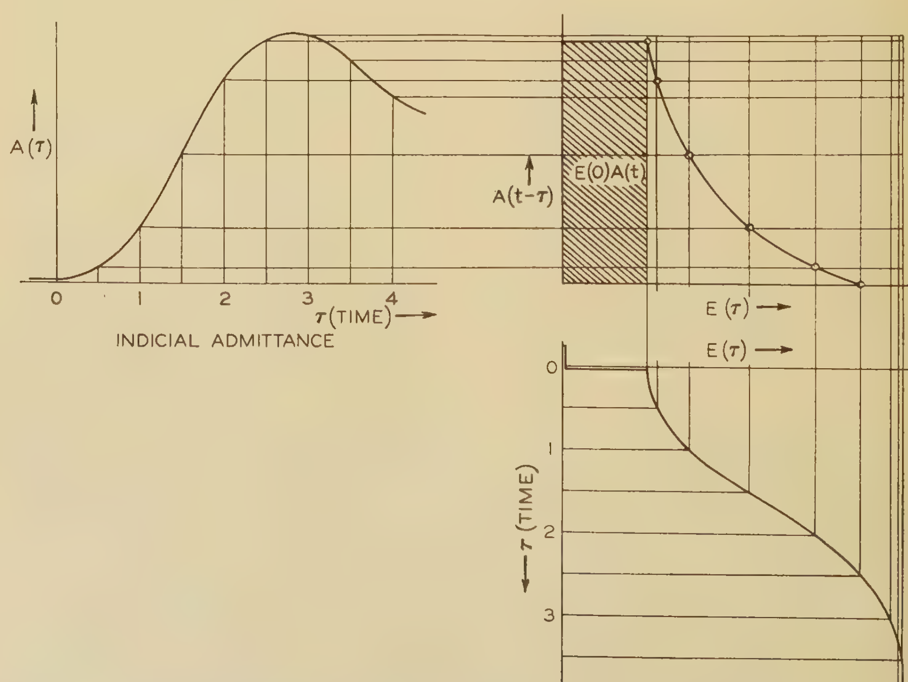



**Figure 1. Graphical solution of Carson's integral**

sponding values of $E(\tau)$ and then measure the area under the curve. A procedure has been developed that makes the work almost mechanical and very rapid. Referring to figure 1, $A(\tau)$ and $E(\tau)$ are plotted so that the $\tau$ axes are perpendicular. Horizontal lines are drawn through points of the $A$ curve corresponding to a series of regularly spaced values of $\tau$. Vertical lines are similarly drawn through points of the $E$ curve corresponding to the same values of $\tau$. Both the vertical and horizontal lines are designated by the corresponding values of $\tau$ and each intersection of a vertical and a horizontal line is designated by the sum of the 2 corresponding values of time, $\tau$. If $I(t)$ is desired for $t = t_1$ a curve is drawn through all intersections designated by the sum $t_1$. The area under this curve is $I(t_1)$. On the diagram, the curve is drawn for $t_1 = 2^1/_2$ seconds. A separate curve evidently results for each instant $t$ at which the value of $I$ is desired. With some care, however, as many as 10 curves can be plotted on a single sheet.

For those interested in the fundamentals of the Heaviside operational calculus, including the application of the above graphical solution of Carson's integral, reference 2 is suggested.

REFERENCES


1. ELECTRIC CIRCUIT THEORY AND THE OPERATIONAL CALCULUS, John R. Carson. McGraw-Hill Book Company, 1926.

2. CALCULATION OF THE MOTION OF AN AIRPLANE UNDER THE INFLUENCE OF IRREGULAR DISTURBANCES, Robert T. Jones, *Journal of the Aeronautical Sciences*, volume 3, 1936, page 419.


Very truly yours,
ALBERT I. NERKEN
Hampton, Va.

## Invention of the Watt-Hour Meter

*To the Editor:*

In the January 1937 issue of ELECTRICAL ENGINEERING, in the paper "Development of a Modern Watt-Hour Meter" by I. F. Kinnard and H. E. Trekell, page 172, lines 6 to 8, the origin of the a-c induction watt-hour meter is ascribed to Shallenberger, in 1894. There is no doubt about Shallenberger's inventing in 1888 (simultaneously with Borel and Paccard in Switzerland) the a-c induction *ampere*-hour meter, but the induction *watt*-hour meter is my invention; see U.S. Patent 423,210, filed October 7, 1889, and issued March 11, 1890. The principle is very clearly explained in lines 88–95 in the first page of specification: ... "the inductive resistance of the shunt winding is very great as compared with its ohmic resistance, its phase of magnetization will be displaced for nearly one quarter of a phase from that of the series magnet. . ."

To get exact quadrature between the 2 magnetic fields, all modern meters have also a shunt path for part of the magnetic flux produced by the voltage coil. Though this was not expressly put forth in the specification, the numerous figures in the patent show it clearly: large pole surfaces provide a considerable amount of stray fields not acting on the meter disk.

In fact, even the first type of meters manufactured by Ganz & Co., from 1889 onwards, had approximately quadrature phase difference between current and voltage fields, though at that remote date this was of no great importance, as loads were nearly exclusively glow lamps and even the earliest meters were sufficiently satisfactory in this respect.

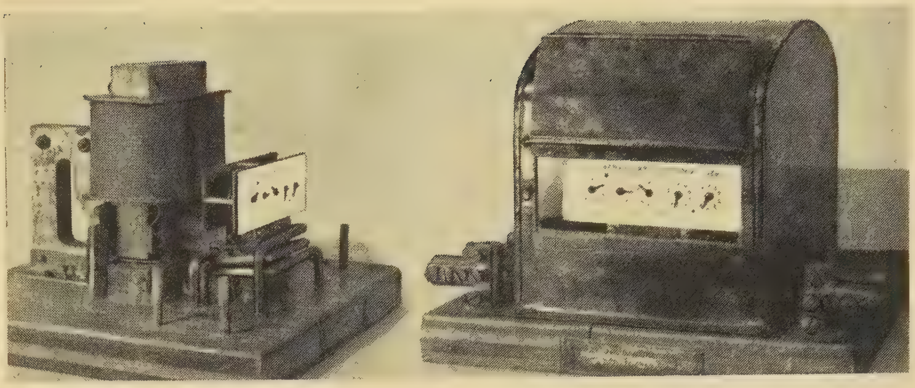


Figure 1. An a-c induction watt-hour meter manufactured in 1893

Meter number 2,157, made in 1893, came back into our museum after about 25 years of service; retested, without adjustment, and taking the 100 per cent load at $\cos\varphi = 1.0$ as unity, it gave the following indications:

| | | | | | | |
|---|---|---|---|---|---|---|
| $\cos\varphi$ | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 |
| slow, % | 0 | 1.6 | 2.5 | 3.5 | 4.5 | 7 0 |

Meter number 52, made in 1889, but with the air-gap of the current field magnet increased from the original 10 millimeters to 20 millimeters (this was usual about a few years afterward, to straighten out the constant curve), everything else unchanged, came back after about 20 years of service; retested, without adjustment, and taking 100 per cent load at unity power factor as unity, it gave the following readings:

| | | | | | |
|---|---|---|---|---|---|
| load, % | 10 | 25 | 50 | 75 | 100 |
| $\cos\varphi = 1.0$ | 1.006 | 1.002 | 1.005 | 1.000 | 1.000 |
| $\cos\varphi = 0.5$ | 1.04 | 1.002 | 1.017 | 1.005 | 1.025 |

Meter number 2,157 is shown in figure 1; "watt-ora" means watt-hours. The torque of these early meters was from 60 to 100 centimeter-grams (600 to 1,000 millimeter-grams). Weight of the rotor was about 100 grams.

One of these earliest induction watt-hour meters is in The Edison Institute at Dearborn, Mich.

Very truly yours,
DOCTOR OTTO T. BLÁTHY
Ganz & Co. Ltd.
Budapest, Hungary

## Electronic Tube Nomenclature

*To the Editor:*

I notice on page 284 of the February 1937 issue of ELECTRICAL ENGINEERING a tabulation of electronic tube nomenclature that is being studied by the American Standards Association.

As comments have been invited, I submit the following point of view:

In connection with the names "kenetron" and "pliotron," would it not be wiser to dispose of these terms and adopt simply the terms "diode," "triode," etc.? This would pave the way for tubes with larger numbers of grids and is in conformity with the present-day practice where we have ascended the scale up to the point of pentode.

If we are to adopt certain terms, such as "pliotron" which have arisen in the industry subsequent to the pioneer work, I wonder if we are keeping pace with the early group of experimenters and inventors. I have in mind, for example, the idea or rather term introduced by DeForest, "the audion." The audion was originally applied by DeForest to the 2-electrode tube or diode and later to his triode. Were we to consider giving credit to DeForest for his invention of the 3-electrode tube, then certainly it would seem that it should carry the term "audion" into our present-day nomenclature. On the other hand, this would naturally raise a question as to whether or not Edison should be associated with the triode and perhaps it will raise a question on the part of some whether or not Fleming should be associated with the diode. Edison gave no term to his 2-electrode tube. However, when Fleming used this particular instrumentality, later, it became popularly known as "the Fleming valve." Since the 2-electrode tube used by Fleming and the 2-electrode hard diode of today are so very nearly the same as Edison's original tube, it would seem to me that any type of personal designation would need to reflect proper credit upon Edison.

An endeavor to give individual inventors credit or individual scientists credit certainly leads to difficulty. Nevertheless, out of deference to these pioneers, we should not adopt comparable terms of a commercial character which, it seems to me, have the unfortunate effect either of making the origin of the devices obscure or leading to a gross misunderstanding.

The great contributions of our telephone company, the Westinghouse Company, the General Electric Company, and others to the vacuum tube art are, of course, well recognized. However, I wonder if it is wise to adopt a term originated by one of these companies if that term carries no more significance with it than just the name. It would seem far better in this case to go over to the impersonal terms, diode, triode, tetrode, pentode, etc. which can raise no question in the minds of many contributors to this art.

Very truly yours,
EDWARD L. BOWLES (A'22, F'33)
Associate Professor of Electrical Communications, Massachusetts Institute of Technology, Cambridge.

# Personal Items

J. W. White (A'29) general manager of the Westinghouse Electric International Company, New York, N. Y., has been elected vice-president and general manager of that company. Mr. White was born at Indianapolis, Ind., in 1889, and received his early education at Randolph-Macon Academy; later, while engaged with the Westinghouse company at East Pittsburgh, Pa., he attended Carnegie Institute of Technology. He joined the Westinghouse Electric & Manufacturing Company, East Pittsburgh, in 1905, and continued at the main works until 1912. In 1917 Mr. White filled the position of manager of the central station and transportation divisions of the Detroit, Mich., offices of that company. His first connection with the export business was in 1918, when he was assigned the managership of the Westinghouse offices at Havana, Cuba. In 1925 he was made managing director of the Westinghouse Company of Japan, with his staff offices at Tokyo. In 1931 Mr. White was made managing director of Cia. Westinghouse Electric International in Argentina, which position he held until he was returned to the United States in 1936 to become general manager of the Westinghouse Electric International Company.

F. W. Smith (A'05, M'12) president, Consolidated Edison Company of New York, Inc., Brooklyn (N. Y.) Edison Company, Inc. and New York and Queens Electric Light and Power Company, has retired. Mr. Smith was born June 16, 1867, at Alden, N. Y., and began his career as an office boy for the United States Illuminating Company in 1880. His service with that company and its successors therefore has spanned a period of almost 57 years; he entered the electrical industry 2 years prior to the opening of the Pearl Street station of the Edison Electric Illuminating Company of New York, and 3 months after the introduction of the incandescent lamp by Thomas A. Edison. In 1883 Mr. Smith became a general clerk and remained in that position until 1889 when he was appointed paymaster for the United Electric Light and Power Company, successor to the United States Illuminating Company. In 1891 he was made assistant auditor of the company, and after remaining in that position for 8 years was elected assistant secretary. A year later he was elected secretary of The Brush Electric Illuminating Company, of which he subsequently became president and a director. In 1905 Mr. Smith was elected secretary of the United Electric Light and Power Company; in 1912 he became vice-president; in 1916, general manager. In 1926 he was elected chairman of the board of directors of the New York and Queens Electric Light and Power Company, and in 1929 became president of The Brush Electric Illuminating Company. Mr. Smith was elected president of The New York Edison Company, Inc., and the United Electric Light and Power Company in 1932; president of the Consolidated Edison Company of New York, Inc., in 1935; and president of the Brooklyn Edison Company, Inc., in 1936. He was active in the affairs of the former National Electric Light Association, and served as vice-president (1919), president (1922), and member and chairman of many of the committees of that organization. He is a member of several technical organizations.

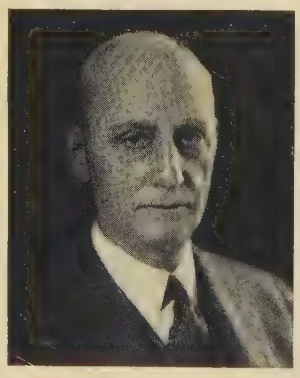
L. B. Fuller (A'03) superintendent of power, Utah Power & Light Company, Salt Lake City, has been appointed chief engineer of the company. Mr. Fuller was born June 14, 1879, at Nelson, Ohio, received a diploma from Hiram College, attended Montana State College, and was graduated from Cornell University in 1906. He had been engaged in engineering work before receiving his formal technical education, and following his graduation was employed as construction superintendent of the Telluride Power Company's Grace, Idaho, hydroelectric plant; upon completion of that plant in 1908 he was transferred to the engineering department of the Telluride Power Company. In 1913 Mr. Fuller was appointed general construction foreman on power house and penstock construction during an extension of the Grace hydroelectric station by the Utah Power & Light Company, successor to the Telluride Company. During 1916–18 he served as construction superintendent on several hydroelectric projects, and in 1919 was appointed general construction superintendent of an extensive hydroelectric and steam-electric project executed by the Phoenix Utility Company for the Utah Power & Light Company. In 1927 Mr. Fuller was appointed assistant superintendent of power of the Utah Power & Light Company; he became superintendent of power in 1929.

J. A. Hale (M'26) formerly chief engineer of the Utah Power & Light Company, Salt Lake City, recently was appointed vice-president of both the Utah Power & Light Company and the Utah Light & Traction Company. Mr. Hale was born September 18, 1888, at Calloway, Va., and received the degree of bachelor of science in civil engineering at Virginia Polytechnic Institute. In 1911 he was appointed junior engineer in the United States Reclamation Service, remaining in that capacity until 1913, when he became affiliated with the Utah Power & Light Company as an assistant engineer. During 1918–19 he served as cost engineer for the United States Housing Corporation, but late in 1919 returned to the Utah Power & Light Company to continue his service with that company without interruption. Mr. Hale was appointed chief engineer in 1927.

E. G. Conroy (A'32) formerly superintendent of radio, City of San Antonio, Texas, now is associated with the bureau of municipal research at the University of Texas, Austin. Mr. Conroy is a native (1907) of San Antonio, and received the degree of bachelor of science in electrical engineering at the University of Notre Dame in 1930. Following his graduation, he entered the long lines department of the American Telephone and Telegraph Company at South Bend, Ind., as a student engineer, and remained with that company until he was appointed supervisor of radio of the City of San Antonio. Mr. Conroy is chairman of the AIEE San Antonio Section.

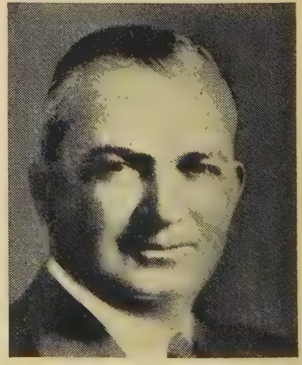
W. H. Burleson (M'31) formerly assistant manager of the power utilities department of the Ohio Brass Company, Mansfield, Ohio, has been appointed manager of that department. Mr. Burleson was graduated from the Texas Agricultural and Mechanical College in 1913, following which he joined the engineering staff of the Texas Power and Light Company and eventually

J. W. WHITE



F. W. SMITH

L. B. FULLER



J. A. HALE

became assistant chief engineer of that company before associating himself with the Ohio Brass Company in 1922. His work with the Ohio Brass Company has required much traveling, and he has visited many utility companies throughout the United States and Canada. Mr. Burleson is chairman of the engineering committee of the high-voltage section of the National Electrical Manufacturers' Association, chairman of the United States Department of Commerce standing committee on simplified practice recommendation 73, covering one-piece insulators, a member of the American Standards Association committee on insulator standardization, and temporary chairman of the ASA subcommittee on suspension-insulator standardization.

L. J. Berberich (A'30, M'36) recently resigned his position as research engineer in charge of cable- and capacitor- oil development for the Socony-Vacuum Oil Company, Incorporated, Paulsboro, N. J., to become a research engineer in the insulation division of the research laboratories of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa. Doctor Berberich was born at Petersburgh, Va., in 1906, and received the degrees of bachelor of engineering (1928) and doctor of engineering (1931) at The Johns Hopkins University. In 1931 he was appointed to the faculty of The Johns Hopkins University, and served as a full-time research assistant, but in the following year he joined the research staff of the Socony-Vacuum Oil Company. He was placed in charge of cable- and capacitor-oil development in 1934. Doctor Berberich is a member of the National Research Council's committee on insulation and the American Society of Testing Materials committee D-9 on electrical insulating materials. He is a member of the American Association for the Advancement of Science and Sigma Xi.

A. J. Johnston (A'32) engineer for the American Totalisator Company, Baltimore, Md., has been transferred to San Mateo, Calif., as manager of the Pacific coast division of that company. Mr. Johnston is a native (1897) of Milwaukie, Ore., and an electrical engineering graduate of Oregon State College. He spent several yeaas in design and application engineering of supervisory control and telemetering equipment for the General Electric Company before becoming affiliated with the American Totalisator Company, and is the author of a paper "The Torque Balance Telemeter," presented at the 1932 AIEE summer convention.

O. L. Riggs (A'21, M'29) formerly superintendent of electric distribution, Lynn (Mass.) Gas and Electric Co., recently was appointed sales manager for the American Electric Service and Maintenance Company, Springfield, Mass. Mr. Riggs entered the employ of the United Electric Light and Power Company, New York, N. Y., as an inspector in 1920, where he remained until 1925 before becoming affiliated with the Lynn Gas and Electric Company.

Paul Narbutovskih (A'32) teaching assistant in electrical engineering, Stanford University, Calif., has been appointed to the faculty of the mathematics department of San Jose State College, San Jose, Calif. Mr. Narbutovskih was born at Tiumen, Russia, in 1902, and received the degree of bachelor of arts at Stanford University in 1929, following which he remained at that institution as a graduate student and teaching assistant. He is the author of a paper, "Tooth-Frequency Eddy-Current Loss," published in the February 1937 issue of Electrical Engineering, pages 253–6.

R. B. Capron (A'30, M'30) assistant distribution engineer, Utica (N. Y.) Gas and Electric Company, has been appointed distribution engineer for the St. Lawrence area of the Niagara Hudson Power Corporation, with headquarters at Potsdam, N. Y. Mr. Capron received the degrees of bachelor of arts (1926) and electrical engineer (1928) from Columbia University, following which he entered the employ of the Utica Gas and Electric Company as a cadet engineer. He became assistant distribution engineer in 1934.

H. R. Anderson (A'27, M'36) formerly assistant electrical engineer for United States Engineers, Fort Peck, Mont., now is employed as transmission engineer for the Loup River Public Power District, Columbus, Nebr. Mr. Anderson, a native (1900) of Huron, S. D., and an electrical engineering graduate of Iowa State College, has had experience in engineering and construction work with several public utility companies.

Alexander Wilson (A'15) assistant to the vice-president in charge of operations Philadelphia (Pa.) Electric Company, has been made operating manager of the company. Mr. Wilson was born at Philadelphia in 1887 and received the degree of mechanical engineer at Cornell University in 1910. Almost immediately following his graduation, he entered the employ of the Philadelphia Electric Company and has since served that company as construction engineer (1918–27), assistant chief engineer (1928–30), and assistant to the vice-president in charge of operations since 1930.

E. H. Colpitts (A'11, F'12) retired vice-president of the Bell Telephone Laboratories, Incorporated, New York, N. Y., recently was awarded the Japanese Fourth Order of Merit of the Sacred Treasure, in recognition of his promotion of electrical engineering in Japan and his furthering of good relations between Japan and the United States. A biographical sketch of Doctor Colpitts appeared in the April 1937 issue of Electrical Engineering at the time of his retirement.

C. C. Long (A'14, M'30) mechanical and electrical construction engineer, Riegos y Fuerza del Ebro, Barcelona, Spain, has returned to the United States. Mr. Long has been in Spain since early in 1930, during which time he has had complete charge of the planning, design, purchase of materials, and construction of a series of hydroelectric stations featuring completely automatic control.

H. H. Krueger (A'21) who has been assistant superintendent of power of the Utah Power & Light Company, Salt Lake City, has been appointed superintendent of power. Mr. Krueger entered the employ of the Utah Power & Light Company in 1914 and in the following 2 years served as operator or maintenance engineer of many of the generating stations and major substations of the interconnected system of that company. After serving as chief dispatcher and as a member of the production and transmission department, he became assistant superintendent of power in 1930.

William Kelly (F'25) president of the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., has been elected a vice-president and director of the newly formed Buffalo Niagara Electric Corporation. A biographical sketch of Colonel Kelly appeared in the February 1937 issue of Electrical Engineering, page 290.

N. I. Korman (Enrolled Student) North Attleboro, Mass., who is enrolled at Worcester Polytechnic Institute, Worcester, Mass., has been awarded a Charles A. Coffin fellowship. Mr. Korman, a native (1916) of Providence, R. I., will pursue research in ultrahigh-frequency measurements at Massachusetts Institute of Technology.

N. R. Gibson (M'32) vice-president of the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., has been elected a vice-president and director of the recently organized Buffalo Niagara Electric Corporation. A biographical sketch of Mr. Gibson appeared in the February 1937 issue of Electrical Engineering, page 290.

D. L. Herr (Enrolled Student) University of Pennsylvania, Philadelphia, has been awarded a Charles A. Coffin fellowship. Mr. Herr is a native (1916) of Ephrata, Pa. He will remain at the University of Pennsylvania to study oscillation in nonlinear circuits.

J. F. Briner, Jr. (A'36) has resigned his position as an under clerk in the Electric Rate Survey, Federal Power Commission, New York, N. Y., to become affiliated with the engineering department of the Niagara, Lockport, and Ontario Power Company, Buffalo, N. Y.

S. M. Zubair (A'27, M'34) formerly an assistant electrical engineer for the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., now is employed by The Tata Hydro-Electric Power Supply Co., Ltd., Bombay, India.

W. T. Elston, Jr. (A'36) has resigned his position as a field engineer for the Central Hudson Gas and Electric Corporation, Kingston, N. Y., to join the research engineering department of the Speer Carbon Company, St. Marys, Pa.

G. S. Onory (A'33) formerly an electrical engineer for the consulting engineering firm of Ford, Bacon, and Davis, New York, N. Y., now is an assistant valuation engineer for the New York State Public Service Commission, with headquarters at Rochester.

R. R. McGee (A'28) formerly employed in the switchgear engineering department of the General Electric Company, Philadelphia, Pa., now is associated with the Trumbull Electric Manufacturing Company, Plainville, Conn.

Robert Loewe (A'32) who has been a surveyor for the Works Progress Administration, Chicago, Ill., now is employed as a transformer design engineer for the Westinghouse Electric & Manufacturing Company, Sharon, Pa.

R. V. Creasy (A'36) who has been an electrical draftsman for the Newport News Shipbuilding and Dry Dock Company, Newport News, Va., now is an equipment engineer for the Western Electric Company, Chicago, Ill.

H. E. Stafford (A'13, M'25) formerly electrical superintendent of the Canadian International Paper Company, Nipigon, Ont., now is employed in the consulting engineering firm of John Stafford, Toronto, Ont.

E. A. Rothfus (A'35) formerly an electrician, United States Engineers, Fort Peck, Mont., now is employed as an electrical tester for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

F. P. Rosso (A'36) city electrical engineer, Cherokee, Okla., Municipal Light and Water Department, now is associated with the Public Service Company of Oklahoma, McAlester, in the commercial lighting department.

J. L. Blackburn (A'36) graduate student, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., recently was transferred to the Newark, N. J., offices of that company.

C. T. Gohn (A'35) clerk, Westinghouse Electric & Manufacturing Company, Philadelphia, Pa., has been transferred to the test engineering department of the East Pittsburgh, Pa., works of that company.

# Obituary

Arthur Williams (A'97, M'08, F'13, member for life) former vice-president of The New York (N. Y.) Edison Company, Inc., died April 14, 1937. Mr. Williams was born August 14, 1868, at Norfolk, Va., and was educated in private schools at New York. He served The New York Edison Company for 42 years, starting as a repair boy in 1885 and retiring in 1928 as vice-president in charge of commercial relations. He became general commercial manager of the company in 1915 and held that position until 1924, when he was made vice-president in charge of commercial relations. In 1917 Mr. Williams was appointed to the post of food administrator for the city of New York; he served in that capacity for 2 1/2 years before resigning in 1920. During the Spanish-American War he served as commanding officer of the New York Volunteer Forces, mining New York Harbor. In 1912 he was decorated by the King of Spain, receiving the rank of knight in the Royal Order of Isabel the Catholic, and in 1926 was made a chevalier of the French Legion of Honor. Mr. Williams was a past-president of the American Association for the Advancement of Science, Association of Edison Illuminating Companies, and the National Electric Light Association; he was also a member of the American Academy of Political and Social Sciences, American Electrochemical Society, American Association for Labor Legislation, International Industrial Relations Association, and Society of American Military Engineers.

Eddy Clifford Jerman (A'20) director of the educational department, General Electric X-Ray Corporation, Chicago Ill., died September 13, 1936, according to word just received at Institute headquarters. Mr. Jerman was born in Ripley County, Indiana, November 21, 1865, and attended Franklin College and Central Business College (Austin, Texas), following which he became associated with the Physicians and Surgeons Supply Company and Jones Brothers Electric Company, both of Cincinnati, Ohio, as an electrician. In 1891 he established his own business at Indianapolis, Ind., at first selling medical and dental electrical supplies; however, in 1896 he began to manufacture X-ray machines. Until 1903 Mr. Jerman acted as an instructor in medical electricity at the Physiomedical College of Indiana and the Central College of Physicians and Surgeons of Indiana; at that time he moved his offices to Topeka, Kans., where he continued the manufacture of electromedical equipment until in 1917 he joined the staff of the Victor X-Ray Corporation, which later became the General Electric X-Ray Corporation, to organize its educational department. Mr. Jerman's service as director of that department covered a period of almost 20 years.

Guy S. Turner (A'18) president, Turner and Turner, Inc., Memphis, Tenn., died in March 1937. Mr. Turner was born April 2, 1876, at Water Valley, Miss. From 1896 to 1898 he served as a machinist for several companies in Texas and in Mexico, and following a year's service with the United States Army Signal Corps during the Spanish-American War, entered the employ of the Memphis Power and Light Company in 1899. He was first a machinist, but became successively electrical foreman, chief electrician, superintendent and mechanical engineer, and engineer in charge of manufacture, remaining with that company until 1920. At that time he established the firm of Turner and Turner, and served as its president for 16 years.

Philip A. Lang (A'88, M'88, member for life) retired engineer, London, England, died February 25, 1937. Mr. Lang was born in October 1856, in Mecklenburg, Germany, and started his technical career as an electrician for Siemens Brothers and Company, Woolwich, England, in 1880. In 1882 Mr. Lang came to the United States and secured a position as head of the testing department of Bergmann and Company, New York, N. Y., where he remained for 4 years before becoming associated with the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., first as an electrician and later as superintendent of the detail department. He was subsequently sent to England as a representative of the Westinghouse company, and eventually became managing director of the British Westinghouse Electric & Manufacturing Company, Trafford Park.

# Membership

## Recommended for Transfer

The board of examiners, at its meeting on May 12, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

### To Grade of Fellow

Pratt, Haraden, vice-president and chief engr., Mackay Radio and Telegraph Co., New York.

1 to Grade of Fellow

### To Grade of Member

Bewley, L. V., electrical engineer, General Electric Company, Pittsfield, Mass.
Dyer, L. L., superintendent of substations, Southern California Edison Company, Los Angeles.
Garin, A. N., electrical engineer, General Electric Company, Pittsfield, Mass.
Goodwin, V. E., managing engineer, lightning arrester, cutout and capacitor department, General Electric Company, Pittsfield, Mass.
Jackson, E. S., electrical distribution engineer, Consumers Power Company, Jackson, Mich.
Pettee, A. D., district engineer, General Cable Corporation, Chicago, Ill.
Pinder, K., electrical engineer, E. I. du Pont de Nemours and Co., Wilmington, Del.
Rey, W. J., electrical engineer, United States Department of the Interior, Washington, D. C.
Roser, J. O. K., assistant to manager, transformer division, General Electric Company, Pittsfield, Mass.
Schott, J. T., telephone engineer, Bell Telephone Laboratories, Incorporated, New York, N. Y.
Underwood, R. J., assistant engineer, New England Power Service Company, Providence, R. I.

11 to Grade of Member

## Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1937, or August 31, 1937, if the applicant resides outside of the United States or Canada.

Adams, E. V., British Columbia Electric Railway Company, Ltd., Vancouver, B. C., Canada.
Alexieff, V. M., Pacific Gas and Electric Company, San Rafael, Calif.
Anspacher, W. B., Union Electric Power and Light Company, St. Louis, Mo.
Arvidson, C. E., Commonwealth and Southern Corporation, Jackson, Mich.
Ballou, R. P. (Member) Allen Bradley Company, Milwaukee, Wis.
Beller, C. J. (Member) Cleveland Electric Illuminating Company, Cleveland, Ohio.

Benkesser, G. E. (Member), Bureau of Power and Light, Los Angeles, Calif.
Bragunier, C. E., Phoenix Engineering Corporation, New York, N. Y.
Brown, G. C. (Member), Cutler-Hammer, Inc., Milwaukee, Wis.
Brown, M. J., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Buswell, M. P., Westinghouse Electric & Manufacturing Company, Seattle, Wash.
Cameron, D. G., General Electric Company, Lynn, Mass.
Campbell, J. F., Consolidated Edison Company, New York, N. Y.
Clay, L. J., Public Service Supply Company, Inc., Cleveland, O.
Cluff, T. W. (Member), Ottawa Electric Company and Ottawa Electric Railway Company, Ottawa, Ont., Canada.
Coburn, W. N., Green Mountain Power Corporation, Bellows Falls, Vt.
Coggeshall, I. S. (Member), Western Union Telegraph Company, New York, N. Y.
Condit, P. A., Pure Oil Company, Chicago, Ill.
Critchley, W. A. (Member), 1730 Ocean Avenue, Brooklyn, N. Y.
Crosby, F. A., Otis Elevator Company, San Francisco, Calif.
Crosby, T. H. (Member), Canadian Westinghouse Company, Ltd., Vancouver, B. C., Canada.
Dailey, J. A. (Member), General Electric Company, Kansas City, Mo.
Dickinson, W. E., 7D Godfrey Court, Fort Riley, Kans.
Diemond, C. C., Bureau of Reclamation, Ephrata, Wash.
Ellerbeck, K. H., Pacific Telephone and Telegraph Company, Seattle, Wash.
Ennis, B. J., Burns and McDonnell Engineering Company, Kansas City, Mo.
Fisken, J. B. (Member), Water Division, City of Spokane, Wash.
Fleischer, F. H., General Electric Company, Fort Wayne, Ind.
Fuller, A. G., Phelps Dodge Corporation, Ajo, Ariz.
Gilman, B. E., L. E. Myers Company, Caro, Mich.
Gosal, G. S., 1731 Allston Way, Berkeley, Calif.
Graham, A. M., Western Union Telegraph Company, Washington, D. C.
Gratz, D. W., Glendale Public Service, Glendale, Calif.
Gronauer, C., Milwaukee Electric Railway and Light Company, Milwaukee, Wis.
Harrison, R. (Member), Scarborough Public Utilities Commission, Toronto, Ont., Canada.
Heiman, H. O. (Member), city engineer's office, Milwaukee, Wis.
Hiers, J. B., Jr. (Member), General Electric Company, Miami, Fla.
Hopwood, J. M., Globe Union, Inc., Milwaukee, Wis.
Howery, H. A. (Member), Kansas City Power and Light Company, Kansas City, Mo.
Hranac, F. V., Unites States Navy Department, Washington, D. C.
Huehnel, A. L., Square D Company, Milwaukee, Wis.
Hughes, M. McC., General Electric Company, Louisville, Ky.
Jones, R. L., Southwestern Bell Telephone Company, Oklahoma City, Okla.
Kalbach, J. F., General Electric Company, Fort Wayne, Ind.
Karg, W. R., Diehl Manufacturing Company, Elizabeth, N. J.
Kinser, J. H., Houston Lighting and Power Company, Houston, Texas.
Kokesh, F. P., Minneapolis-St. Paul Sanitary District, St. Paul, Minn.
Kunz, A. F., Ohio Bell Telephone Company, Cleveland, O.
Lauder, A., Phillips Electrical Works, Ltd., Brockville, Ont., Canada.
Mallett, M. B. (Member), General Electric Company, Pittsfield, Mass.
McCall, R. L. (Member), substations and water department, Jacksonville, Fla.
Meichel, C. B. (Member), Department of Public Utilities, St. Louis, Mo.
Mergenthaler, A. H. (Member), Alabama Power Company, Birmingham.
Merkel, N. M., Metropolitan Edison Company, Reading, Pa.
Meyers, W. N., Federal Shipbuilding and Drydock Company, New York, N. Y.
Miller, G. R., Metropolitan Water District of Southern California, Rice, Calif.
Myers, H. C., Government Printing Office, Washington, D. C.
Osborne, H. R., Ferranti Electric, Ltd., Toronto, Ont., Canada.
Osgood, D. T., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Osterhout, E. W., New Jersey Zinc Company, Franklin, N. J.
Pacanins, A., Hillcrest Hotel, Toledo, O.
Penn, L., Travelers Insurance Company, New York, N. Y.
Pennington, C. C., Tennessee Valley Authority, Chattanooga, Tenn.
Perkins, W. S., General Electric Company, Bridgeport, Conn.
Pickles, S. B., Gardner Electric Manufacturing Company, Emeryville, Calif.
Ramadanoff, D. (Member), Cornell University, Ithaca, N. Y.
Ramien, C. H., Jr., Globe Union, Inc., Milwaukee, Wis.
Reeves, G. A., Jr., Oklahoma Gas and Electric Company, Oklahoma City, Okla.
Robbins, C. F., Cutler-Hammer, Inc., Milwaukee, Wis.
Rohlfsen, A. G., Johns-Manville Products Corporation, Lompoc, Calif.
Schmidt, I. F., Milwaukee Electric Railway and Light Company, Milwaukee, Wis.
Schnabel, J. F. (Member), Euclid Electric an Manufacturing Company, Euclid, Ohio.
Schoen, A. M., Commonwealth and Southern Corporation, Jackson, Mich.
Shuman, U. S., Philadelphia Electric Company, Philadelphia, Pa.
Smith, C., New York and Queens Electric Light and Power Company, Flushing, N. Y.
Smith, C. G., Smith Milligan Electric Company, Tulsa, Okla.
Spitler, C. H., Brown-Brockmeyer Company, Inc., Dayton, O.
Stark, O. P., Jr., Hoosier Engineering Company, Columbus, Ohio.
Steel, H. D., Herman D. Steel Company, Philadelphia, Pa.
Stevenson, R. B., Dollar Steamship Company, San Francisco, Calif.
Stodola, F. J., Milwaukee Electric Railway and Light Company, Milwaukee, Wis.
Thwaites, J. T., Canadian Westinghouse Company, Hamilton, Ont., Canada.
Tibbals, L., Colonial Radio Corporation, Buffalo, N. Y.
Tracy, J. B., Jr., Radio Experimental Laboratories, Taunton, Mass.
Ullman, F. (Member), Westinghouse Electric & Manufacturing Company, New York, N. Y.
Vialet, F. C., 2257—7th Avenue, New York, N. Y.
Wedge, R. E., General Electric Company, Fort Wayne, Indiana.
Wells, C. A., Southern California Telephone Company, Los Angeles, Calif.
Younger, D., American Telephone and Telegraph Company, Buffalo, N. Y.
Zigler, M. O., Federal Power Commission, Denver, Colo.

91 Domestic

**Foreign**

Channa, B. N., Public Works Department, Jogindernager, Mandi State, India.
Drake, H. H., Indian Iron and Steel Company, Ltd., Burnpur, India.
Gademann, O. M., Allgemeine Elektricitäts-Gesellschaft, Berlin, Germany.
Koo, C. T., Shanghai Power Company, Shanghai, China
Martinez G. R., La Consolidada, S. A., Calzada de la Ronda, Mexico, D. F., Mexico.
Russell, A. J. G., 256 St. Asaph Street, Christchurch, New Zealand.
Smyth, L. C., Cerro de Pasco Copper Corporation, Oroya, Peru.
Shima, R., Toden Electric Supplies Company, To yo, Japan.
Warburton, J. H., Edison Swan Cables, Ltd., L don, England.

9 Foreign

# Engineering Literature

## New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

MUNICIPAL YEAR BOOK. 1937. Edited by C. E. Ridley and O. F. Nolting. Chicago, International City Managers' Association, 1937. 599 pages, illustrated, 10x7 inches, cloth, $5.00. Contains articles on developments in various fields of municipal administration and gives statistics on cities over 10,000. Lists educational institutions giving courses in public administration and includes a directory of city officials in all cities over 10,000.

MEN of MATHEMATICS. By E. T. Bell. New York, Simon and Schuster, 1937. 592 pages, illustrated, 10x6 inches, cloth, $5.00. Biographical and critical information about the important men in the mathematical field, from the Greeks to the present time.

### Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

FIRST ELEVATED RAILROADS in MANHATTAN and the BRONX of the CITY of NEW YORK. By W. F. Reeves. New York, New York Historical Society, 1936. 137 pages, illustrated, 10x7 inches, cloth, $3.00. Description of the development and progress of the early elevated railroads in Manhattan and the Bronx, including the various schemes proposed from 1825 up to the first actual construction in 1867.

JOURNAL of the ROYAL TECHNICAL COLLEGE, volume 4, part 1, January, 1937. Glasgow, Royal Technical College. 212 pages, illustrated, 10x7 inches, paper, 10s. 6d. Contains several papers of interest to electrical engineers, including a discussion of the sensitivity of the Schering bridge network and the commutation period in grid-controlled mercury-arc rectifiers.

THEORIE der WECHSELSTROMMASCHINEN in Vektorieller Darstellung. By W. Michael. Leipzig und Berlin, B. G. Teubner, 1937. 272 pages, illustrated 10x6 inches, paper, 16.50 rm.; bound, 18 rm. (in U.S.A.). Develops the theory of a-c machines by means of "space diagrams" and "space vector diagrams." Includes chapters on transformers, induction machines, commutator motors, auxiliary machines, and cascade connections between induction and commutator machines.

OBJECTIVE RATE PLAN for Reducing the Price of Residential Electricity. By W. F. Kennedy. New York, Columbia University Press, 1937. 83 pages, charts, tables, 9x6 inches, cloth, $1.25. Relates the history of the plan, the reasons for its adoption and the results obtained.

COMPENSATING INDUSTRIAL EFFORT. By Z. C. Dickinson. New York, Ronald Press Company, 1937. 479 pages, illustrated, 9x6 inches, cloth, $4.50. A study of the problem of work incentives. Covers the causes determining the amount of wages of occupations and individuals, the relative efficacy of various stimuli and factors in increasing production, and the social consequences of various work-and-pay situations.

ALTERNATING CURRENTS in RADIO RECEIVERS. By J. F. Rider. Published by author, 1440 Broadway, New York, N. Y., 1937. 94 pages, illustrated, 9x6 inches, paper, $0.60. A discussion of basic facts about alternating currents in radio receivers.

AMERICAN SOCIETY for TESTING MATERIALS. INDEX to PROCEEDINGS, volumes 31–35 (1931–35). Philadelphia, American Society for Testing Materials, 1937. 194 pages, 9x6 inches, cloth, $2.25; half leather, $3.00. Contains author and subject indexes for the *Proceedings* of 1931–1935 and of the symposiums presented at regional, local, and annual meetings, and not published in the *Proceedings*.

APPLICATIONS of the METHOD of SYMMETRICAL COMPONENTS. (Electrical Engineering Texts.) By W. V. Lyon. New York and London, McGraw-Hill Book Company, 1937. 579 pages, illustrated, 9x6 inches, cloth, $6.00. Designed to demonstrate the use of symmetrical components in the solution of problems in unsymmetrical polyphase circuits. The reader is expected to have a thorough grounding in single-phase and symmetrical polyphase circuits, transformers, and symmetrical operation of 3-phase induction and synchronous machines.

GÉNÉRATRICES et MOTEURS à courant continu. By E. Roth and J. Bardin. Paris, Librairie Armand Colin, 1937. 223 pages, illustrated, 7x5 inches, paper, 13 frs.; bound, 15.50 frs. Presents the principles of d-c machines, written in easily understood language and intended for students and designers.

# Industrial Notes

**Building Construction Still Upward.**—Not since May 1930 has residential building been undertaken in such heavy volume as was reported in April this year, according to F. W. Dodge Corp. The value of such operations started during April in the 37 states east of the Rocky Mountains amounted to $108,204,400, a gain of 20 per cent over the March figure and an increase of 61 per cent over April 1936. Besides residential building, the April 1937 figures show $96,179,300 for non-residential building and $65,741,500 for heavy engineering projects, i. e., public works and public utilities.

**U. S. Rubber Appoints Dr. Sturdevant.**—According to a recent announcement United States Rubber Products, Inc., has appointed Dr. Earl G. Sturdevant as consulting engineer of its electrical wire and cable dept. Dr. Sturdevant joined the company in 1929, being previously connected with the Western Electric Co. In 1931 he was appointed development manager of the electrical wire and cable department, where he contributed to the successful development of Laytex, the new dielectric.

**New Branch Manager for Weston.**—H. E. Held has recently been appointed to succeed the late C. F. Henderson as manager of the San Francisco agency of the Weston Electrical Instrument Corporation, with offices at 420 Market St. Mr. Held was previously assistant to Mr. Henderson for a number of years.

**Resistance Wire Division Sold.**—The C. O. Jelliff Mfg. Corp., Southport, Conn., has recently purchased the resistance wire division of George W. Prentiss and Co., of Holyoke, Mass.

**Century Electric Moves New York Office.**—The New York office of the Century Electric Co. has been moved from 50 Church St. into larger quarters in the Underwood Building, 30 Vesey St. James Larkin is district sales manager.

**Frigidaire Plants Enlarged.**—The erection of 2 new factory buildings, together with enlargement and rearrangement of the Moraine City, O., manufacturing facilities of Frigidaire Div., General Motors Corp., will be started shortly. The construction and plant layout program will involve an expenditure in excess of $4,000,000.

**New Oil Blast Circuit Breaker.**—A new oil blast circuit breaker, type FK-45, with 75,000 kv-a interrupting rating has been announced by the General Electric Co. The FK-45 unit is a non-oil-throwing breaker with plate steel rectangular tank with separating chamber, internal mechanism, silver-to-silver main contacts, easily renewable arcing contacts, oil blast baffles, and Herkolite bushings. It is available in three current sizes, 600, 1200 and 2000 amperes. A feature of the new breaker is its sturdy tank construction which makes it especially applicable where heavy duty and small space requirements are indicated.

**New Type Motor Starter.**—The Allis-Chalmers Manufacturing Co., Condit Works Boston, Mass., announces a new type of across-the-line air motor-starter, equipped with "Ruptors," known as type AP-7. The Ruptors are enclosing chambers which confine and depotentiate the arc formed by circuit interruption. These "arc-depotentiating chambers" greatly increase the interrupting ability of the contacts and form an isolating barrier between contacts of opposite polarity. The starter is furnished for $7^1/_2$ hp at 440 and 550 volts, 5 hp at 220 volts, and 3 hp at 110 volts.

**New G-E Building in Los Angeles.**—Contracts were recently awarded for the construction of a new $700,000 General Electric building at Los Angeles. The new building is designed to contain 6 stories and basement, 3 stories of which are planned to be completed for occupancy by September. The new structure will occupy approximately a city block in the downtown section of Los Angeles and will contain 250,000 square feet of floor space.

# Trade Literature

**Capacitors.**—Catalog 139A. Describes new pole-type capacitors for power correction of distribution systems. Cornell-Dubilier Corp., South Plainfield, N. J.

**Fire Alarm Systems.**—Bulletin 102, 16 pp. Describes Samson fire alarm systems for institutions, factories, etc. S. H. Couch Co., Inc., North Quincy, Mass.

**Watthour Meters.**—Bulletin GEA-2404A, 16 pp. Describes 2-element, single-disk watthour meters, their mountings, connection diagrams, etc. General Electric Co., Schenectady, N. Y.

**Underground Conduit.**—Bulletin 3751, 16 pp. Describes fibre conduit, standard and thin wall, together with fittings. Line Material Co., So. Milwaukee, Wis.

**Heating Units.**—Bulletin GED-650, 60 pp. Describes numerous small heating units and devices of all kinds for a wide variety of applications. General Electric Co., Schenectady, N. Y.

**Flexible Metal Tubing.**—Bulletin SS-3, 16 pp. Describes seamless flexible metal tubing, one of the 4 major styles of flexible metal hose made by this company. Illustrates a wide variety of installations where absolute tightness in conveying liquids or gases is essential. The American Brass Co., American Metal Hose Branch, Waterbury, Conn.

**Pulleys and Couplings.**—Bulletin, 4 pp. Describes a complete line of "V" grooved pulleys, variable speed and step-cone pulleys; flexible couplings. Congress Tool & Die Co., Inc., 9030 Lumpkin Ave., Detroit, Mich.

**Flow Meters.**—Catalog, 40 pp. Describes electrical and mechanical flow meters for recording, integrating, controlling and indicating the flow of steam, liquids, or gases. Details of the new electric flow meter and its operation, using Bristol's metameter principle of telemetering, are included. The Bristol Co., Waterbury, Conn.

**Service Cables.**—Bulletin C-31, 20 pp. Describes various types of service cables, illustrating uses and installations permitted by the National Electric Code. Typical applications and specifications are included. Anaconda Cable and Wire Co., 25 Broadway, New York City.

**Lightning Protective Equipment.**—Bulletin GEA-1743B, 12 pp. Describes lightning protective equipment for a-c rotating machines insuring protection against traveling-wave voltages due to lightning. The protective arrangement covers the combined use of arresters and capacitors. General Electric Co., Schenectady, N. Y.

**Motors.**—Bulletin 305. Describes Reliance disc-brake motors,—combined units for power applications requiring quick, accurate, automatic stops or the holding of a load. Typical applications are small cranes, hoists, and auxiliary movements on machine tools. They frequently eliminate the need for clutches and permit direct connection of motors. Reliance Electric & Engineering Co., 1086 Ivanhoe Rd., Cleveland, O.

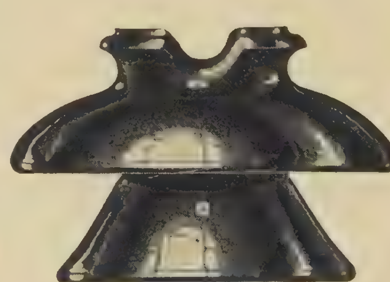
**Arc Welders.**—Bulletin "The Arc-Welding of Tomorrow." Describes the advantages gained by the use of the internally stabilized arc of the "Smootharc Welder." Photographs illustrate the applications of many of the models, from the vertical 75- and 100-ampere types to the 200-, 300-, 400- and 600-ampere horizontal types. Stationary and portable-trailer models are also shown. Harnischfeger Corp., 4200 W. National Ave., Milwaukee, Wis.

**Transformers.**—Bulletin 340, 8 pp. Describes power and distribution transformers, illustrating various types of large equipment, single phase and three phase, used for power transmission, electric arc furnaces, railway systems, or other industrial purposes. Brief mention is made of a few of the important developments and improvements, such as uni-row radiators, straight line tap-changers, circular coils, etc. Pennsylvania Transformer Co., 1701 Island Ave., N. S., Pittsburgh, Pa.

**Voltage Regulators.**—Bulletin 5601, 8 pp., Electronic Automatic Alternator Voltage Regulator, Type EF. Describes and illustrates this type of regulator which can be used with any known method of excitation. It explains in detail the operation of this comparatively new method of automatic voltage regulation. Bulletin 5602, 8 pp. Describes a similar regulator designed for only one scheme of excitation, i. e., one regulator for each exciter. Ward Leonard Electric Co., Mt. Vernon, N. Y.

*(Cont'd on page 21)*

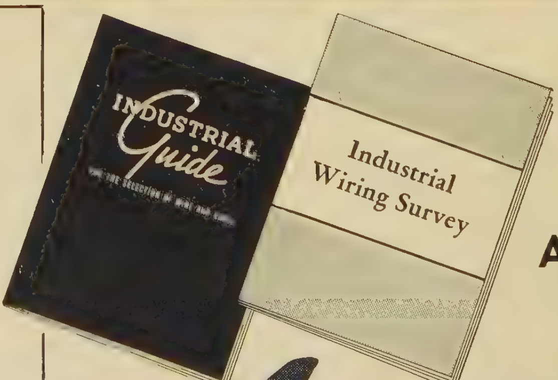





## Two important books which you should have

One is our "Industrial Wiring Survey". This volume tell you how to initiate a scientific check-up of electrical circuits. It simplifies the problem surprisingly.

The other is our "Industrial Guide for the Selection of Wire and Cable". Brand new, it is the only thing of its kind in the electrical industry. Scores of situations are described and an engineering recommendation is given for the correct wiring solution of each. Write for your copies.




ANACONDA
from mine to consumer
REG. U.S. PAT. OFF.

Anaconda

General Offices: 25 Broadway, New York

# COORDINATED INSULATION *protects* OP CURRENT TRANSFORMERS

The Type OP Current Transformer, designed particularly for outdoor substation construction, now features scientifically coordinated insulation. Affording a most effective safeguard against impulse, or lightning, surges, coordinated insulation performs three valuable services for you . . .

1 Reduces Maintenance
2 Eliminates Costly Service Interruptions
3 Protects your Capital Investment

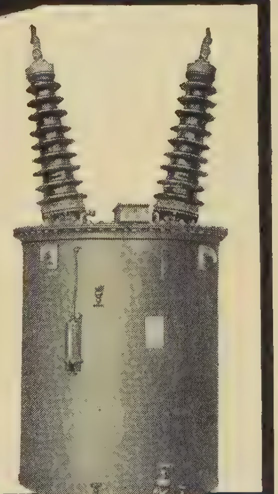
And, as an added protection, small, low-voltage Autovalve lightning arresters, mounted at the top of the condenser bushing, guard the primary winding.

All ratings of the Type OP current transformer have series-parallel primary windings which give two ratios on the secondary side. If required, double secondaries can be supplied, permitting very accurate metering on one secondary, and relay or breaker operation on the other.

Type OP Transformers are available for primary voltages up to 161,000 volts; in currents ratio up to 800—5 amperes. J 70043

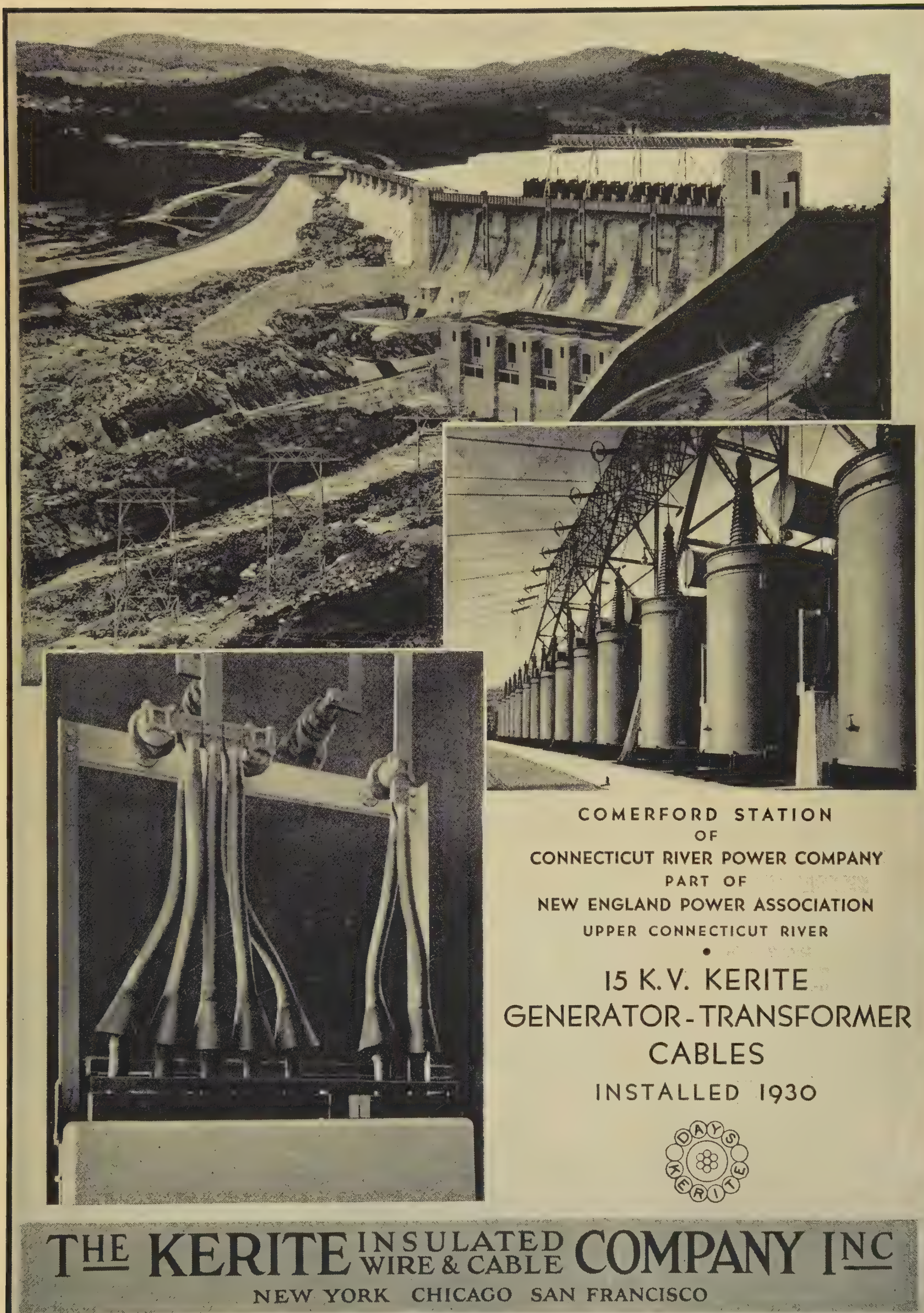
For more detailed information on these or other Westinghouse Transformers, contact the nearest Westinghouse Representative or address Westinghouse Electric & Manufacturing Company, Room 7-N, East Pittsburgh, Pa.

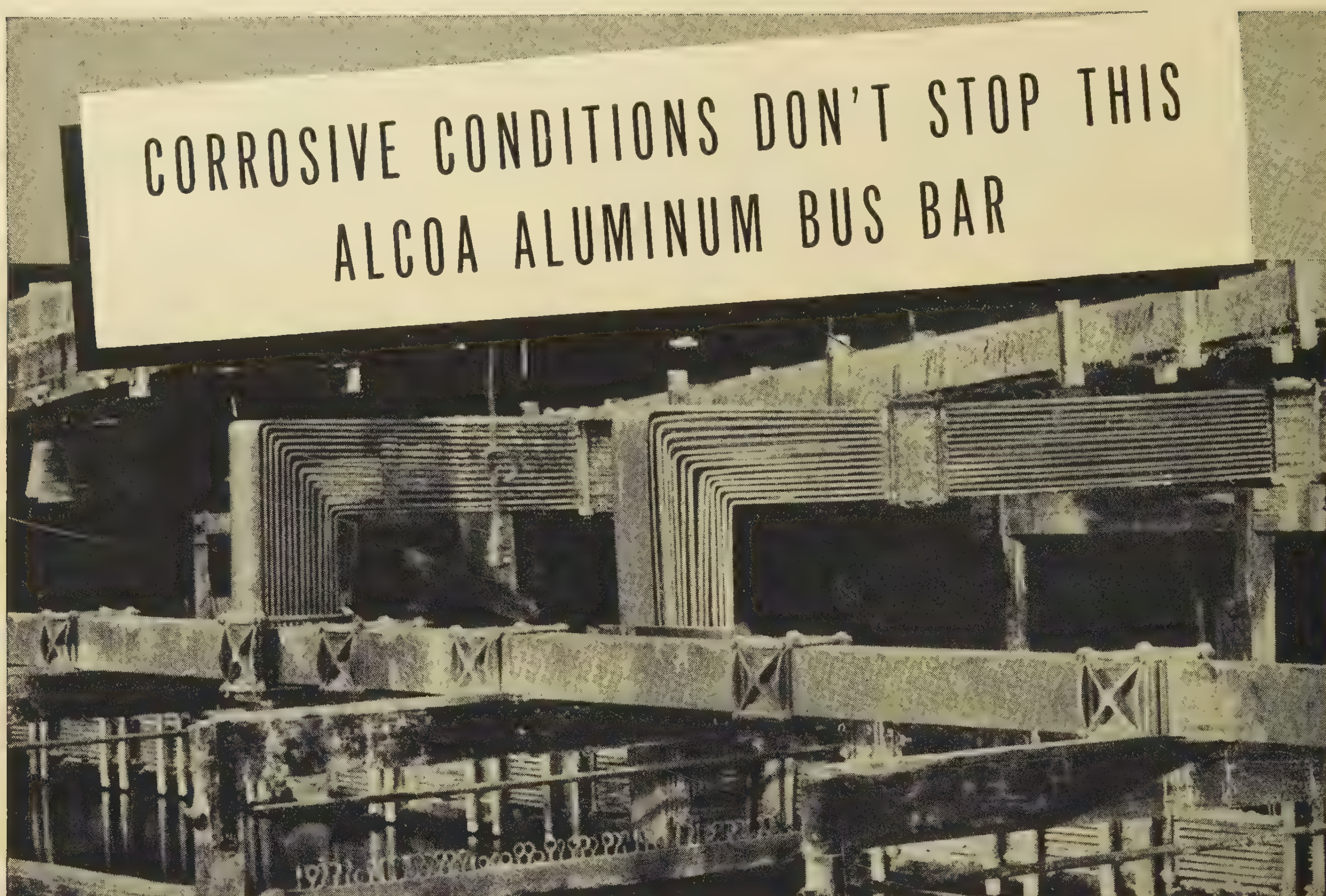
The Type VP *Potential* Transformer, companion to the Type OP, is also protected by completely coordinated insulation. It is built to the same rigid standards as Westinghouse Power Transformers. Ratings up to 161,000/115 volts.



WESTINGHOUSE ELECTRIC

**Westinghouse**


COMERFORD STATION
OF
CONNECTICUT RIVER POWER COMPANY
PART OF
NEW ENGLAND POWER ASSOCIATION
UPPER CONNECTICUT RIVER
15 K.V. KERITE
GENERATOR-TRANSFORMER
CABLES
INSTALLED 1930
DAYS KERITE
THE KERITE INSULATED WIRE & CABLE COMPANY INC
NEW YORK CHICAGO SAN FRANCISCO




Alcoa Aluminum Flat Bus Bar installed on plating tanks of Crescent Armored Wire Company, Trenton, New Jersey. In use since 1930.

For seven years this plating tank has been operated with Alcoa Aluminum Bus as shown. Under these severely corrosive conditions the bus has given efficient, trouble-free service.

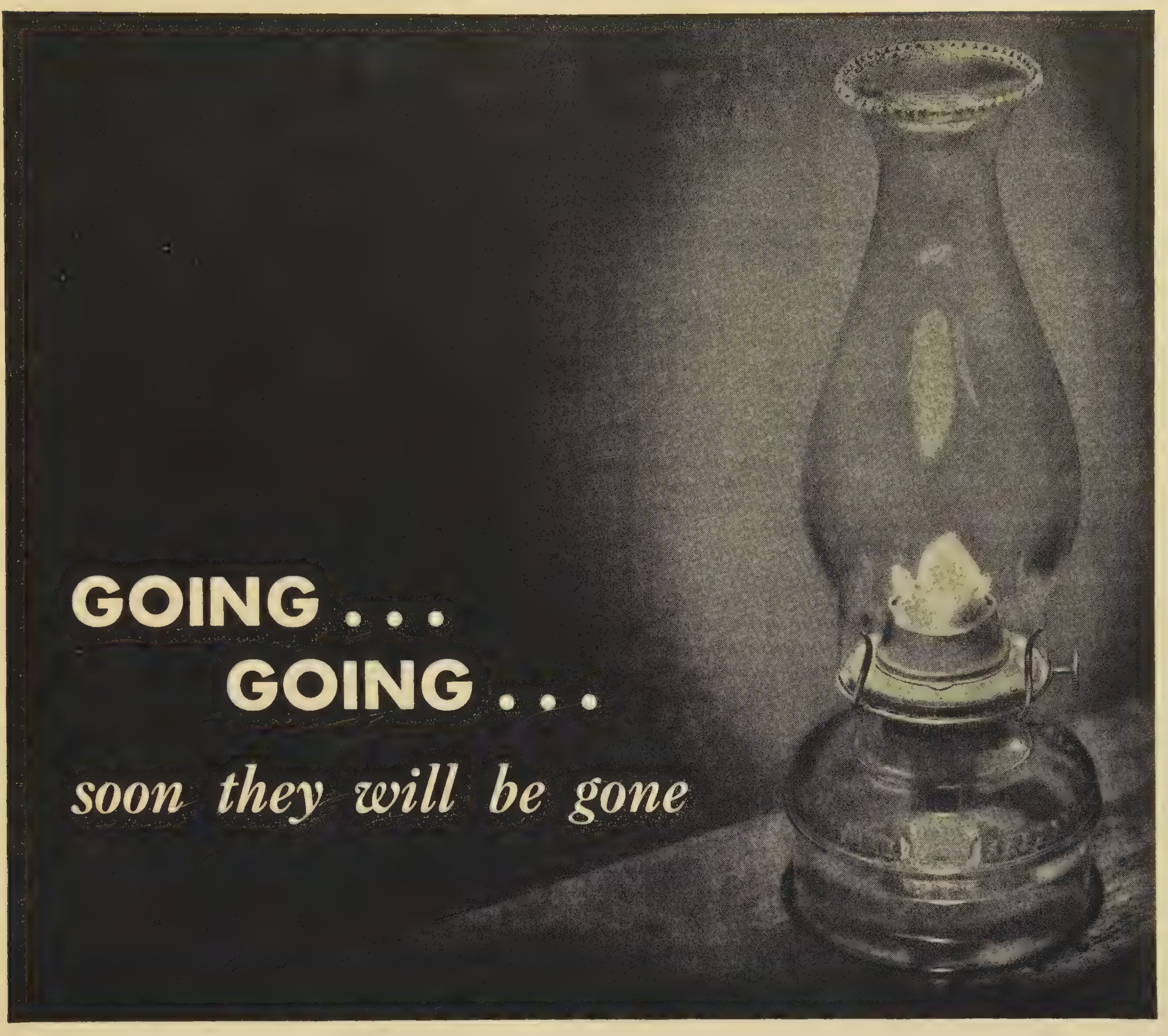
Resistance to common types of corrosion is a natural, inherent characteristic of Aluminum. Properly installed runs of Alcoa Bus stand up year after year with virtually no attention in spite of fume from sulphuric acid, cyanide baths, and other corrosive agents. Interruptions are prevented. Money is saved.

Another basic saving results from the fact that Alcoa Bus is easy to install. The metal is easily worked, fittings are simple and inexpensive, and lightness permits the most economical overhead disposition with minimum expenditure for supports. Joints are readily made by bolting or welding.

Alcoa Aluminum Bus comes in three forms: flats and tubes for the usual types of construction, and Channeluminum, the strong rolled channel section which is more efficient for heavy currents. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh, Pa.

ALCOA ALUMINUM Reg. U. S. Pat. Off.

# ALCOA · ALUMINUM




ELECTRICITY is going to work for the rural population. The thousands of miles of electrical lines which are now being installed require the use of nearly every type of electrical wire and cable. Engineering problems have made new designs necessary to meet varying conditions.

We have been making electrical wires and cables for many, many years. During that time most of the problems of electrification have been put before our engineers. Our experience and research facilities combined have been successfully called upon in the development of new materials to meet changing requirements.

Look to the American Steel & Wire Company for electrical wires and cables of every description. Our reputation for quality has been built on more than a century of wire-making experience. We welcome the opportunity to be of practical assistance to you in working out your needs for electrical wires and cables, and we are able to supply these needs with products that will give complete service and economy.

***American Steel & Wire Company Products for Rural Electrification Projects***

Galvanized Steel Conductors · Guy and Messenger Wire · Bare Copper Wire and Strand · Reliance URC Weatherproof Wire · Copperweld-Copper · Service Entrance & Drop Cables · Underground High Voltage Primary Cables · Overhead Concentric Cables · Rubber Covered Wires

# ELECTRICAL WIRES AND CABLES

AMERICAN STEEL & WIRE COMPANY

208 South La Salle Street, Chicago

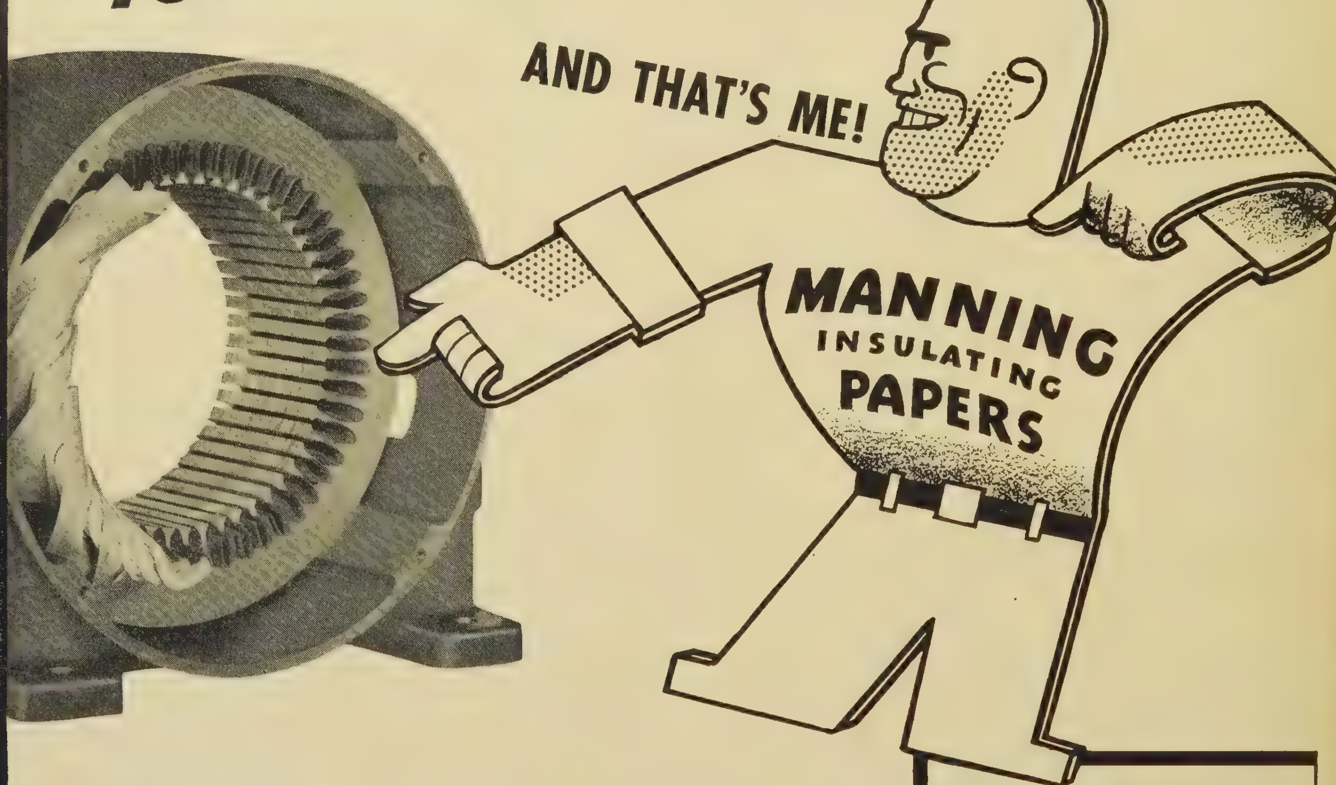
Columbia Steel Company, San Francisco, *Pacific Coast Distributors*

Empire State Building, New York

United States Steel Products Company, New York, *Export Distributors*

UNITED STATES STEEL

# "TO PREVENT GROUND FAILURES YOU GOTTA USE A TOUGH PAPER"



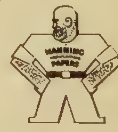

To protect coil windings at the end of the slots, where most grounds occur, a slot insulating paper, above all things, must be *tough*. It must resist puncture and abrasion. It must withstand the pull of the wire as the winding is being shaped and pounded into place—without splitting, cracking, or de-laminating. Laboratory tests and performance records prove the unusual toughness and stretching qualities of Manning 300 and Manning B high-density insulating papers.

Unusually high dielectric strength has been built into these Manning papers. Their high density is obtained by a special mechanical process—not by the use of chemicals. No coloring or sizing is used in the manufacture of these papers. They will withstand high temperatures without cracking or becoming brittle. The John A. Manning Paper Company is a recognized leader in the manufacture of insulating paper. To prevent ground failures, specify Manning papers and be safe.

**MANNING 300**
—Highest quality, non-chemical, all-rag paper. Extremely tough, chemically pure, superior heat aging qualities. Each sheet is given an over-all dielectric test at 300 volts per mil.

**MANNING B**
—Highest quality, non-chemical, 50% rag paper. Made by the same process as Manning 300. A high-density paper of unusual quality at a lower price.

**WRITE FOR SAMPLE CUT-OUT**

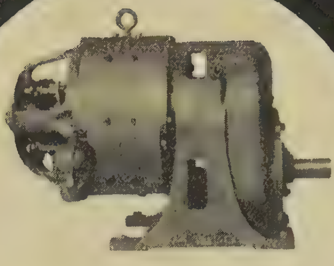


**INSULATION MANUFACTURERS CORPORATION**
565 West Washington Blvd., Chicago, Illinois
CLEVELAND • DETROIT • MILWAUKEE • MINNEAPOLIS • PEORIA

ELECTRICAL IMC INSULATION

| OTHER MANNING DISTRIBUTORS: | Pittsburgh | St. Louis | Los Angeles | San Francisco | Seattle | Philadelphia |
|---|---|---|---|---|---|---|
| | Earl B. Beach Co. | Insulation, Inc. | Mr. C. D. LaMoree | Mr. C. D. LaMoree | Mr. C. D. LaMoree | Staub-Towle Co. |
| | Oliver Bldg. | 2127 Pine St. | 1325 San Julian St. | 1889 Mission St. | 305 First Ave., So. | 18 W. Chelton Ave. |

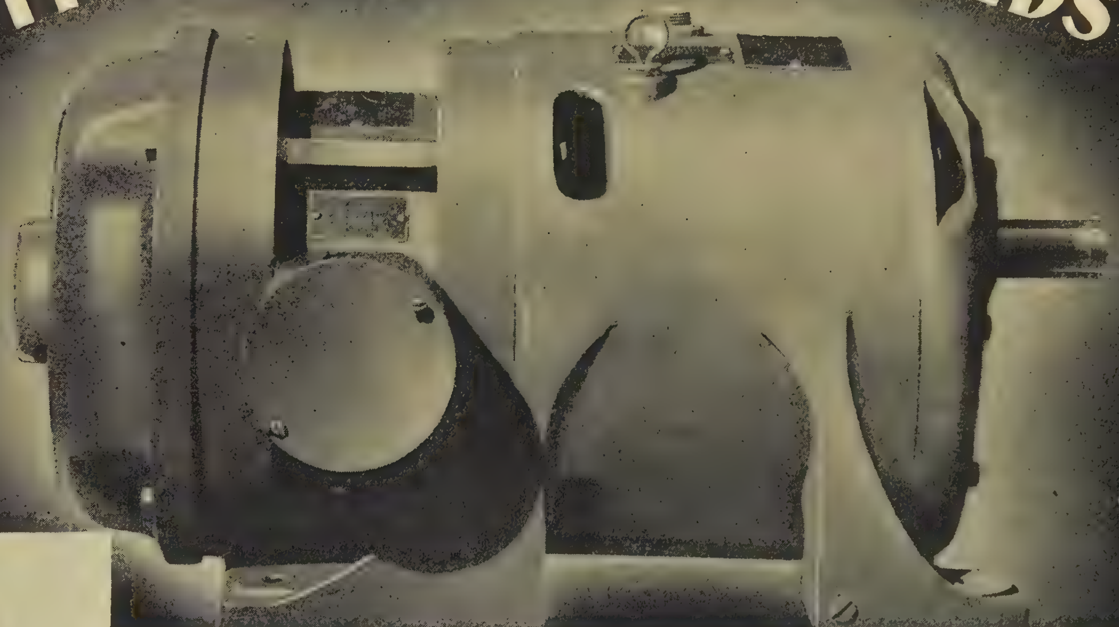
Double-reduction unit with fan-cooled squirrel-cage motor for use in dirty locations.



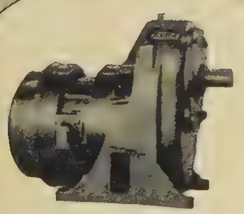
Single-reduction Reliance Gearmotor with open type direct-current motor.

An alternating-current wound-rotor motor is used for this single-stage gearmotor. Drive shaft at bottom.

# RELIANCE GEARMOTORS TO FIT YOUR *Peculiar* NEEDS



**Type S Reliance Gearmotor**
Open Squirrel-cage Motor Unit
Double Reduction



Single-reduction Gearmotor with open squirrel-cage a-c. motor. Drive shaft at top.

This splash-proof motor unit provides low cost but effective protection against dripping and splashing liquids.

Reliance Gearmotors are constructed on a sound principle, combining motor and speed reducer into one efficient, space-saving unit. The simplicity of Reliance design facilitates taking apart and assembling. There's plenty of strength and liberal support where most needed . . . To fit exactly those needs which are peculiar to your work, Reliance Gearmotors are made in a wide range of ratios—in constant-speed, multi-speed, and adjustable-speed types—in open, splash-proof, enclosed fan-cooled, and pipe-ventilated styles . . . Reliance engineers will undertake to meet your individual requirements with recommendations just as specialized, to insure the minimum in first cost, installation and maintenance *and* the maximum in production. See Bulletin 400.

RELIANCE ELECTRIC & ENGINEERING COMPANY
1086 Ivanhoe Road — Cleveland, Ohio

Branches: Birmingham, Boston, Buffalo, Chicago, Cincinnati, Detroit, Greenville (S. C.), New York, Philadelphia, Pittsburgh. *Representatives in other principal cities.*

# RELIANCE A-C D-C MOTORS

# *Uniformly Low* CORE LOSSES

## NEWS FOR ELECTRICAL ENGINEERS

### GUARANTEED MAXIMUM CORE LOSSES

Watts per Pound at 60 Cycles and 10,000 Gausses
Epstein Test
According to A. S. T. M. Standard Methods A-34
Issued March 15, 1937

| | U. S. STANDARD GAUGE NUMBER | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GRADE | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| USS Armature.......... | 2.50 | 2.23 | 1.98 | 1.75 | 1.55 | 1.46 | 1.38 | 1.30 |
| USS Electrical* ........ | 2.17 | 1.94 | 1.70 | 1.50 | 1.35 | 1.29 | 1.23 | 1.17 |
| USS Motor*........... | | | 1.30 | 1.22 | 1.14 | 1.09 | 1.05 | 1.01 |
| USS Dynamo* ......... | | | 1.10 | 1.02 | .94 | .90 | .86 | .82 |
| USS Radio Transformer 72 | | | .97 | .90 | .83 | .80 | .76 | .72 |
| USS Transformer 72*.... | | | .97 | .90 | .83 | .80 | .76 | .72 |
| USS Transformer 65 ....... | | | | | | | | .65 |
| USS Transformer 58 ....... | | | | | | | | .58 |

* These grades are available in thicknesses of .010, .007, .005 and .003 inches, for use at frequencies higher than power frequencies. Your inquiries are solicited.

IN THE INSPECTION *of this armature core for a direct current motor, the skilled workman is examining each slot. The manufacturer specifies USS Electrical because they are uniform — in electrical and physical characteristics.*

# CLASSIFIED ADVERTISEMENTS

*RATES: Fifty cents per line; minimum charge based on use of five lines. Copy is due the 15th of the month preceding publication date.*

WANTED: Copies of October (1936) issue of ELECTRICAL ENGINEERING. Please mail (parcel post) to American Institute of Electrical Engineers, 33 West 39th St., New York City, printing your name and address upon enclosing wrapper. Twenty-five cents, plus postage, will be paid for each copy returned.

TRANSFORMERS FOR SALE: Three 75-kva transformers, 11,000 to 230 or 460 volts; one 15-kva lighting transformer. Make us an offer. Central Electric Company, Hattiesburg, Miss.

ELECTRIC TUBE WELDING ENGINEER: Experienced regarding patent conditions, welding theory, welder and former design. Save time and cost of developing engineers to study involved problems requiring actual experience. Avoid known mistakes. Avoid royalties if possible. Address Box 182, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

WANTED: Young man with engineering education and experience in power and public utility industry to train for position of Sales Engineer for well-known manufacturer of recording voltmeters, ammeters and wattmeters and telemetering systems. Must have outstanding personality and be free for extensive traveling and quick transfers. Highest character references required. Write stating age, education, experience and salary desired. Address Box 183, ELECTRICAL ENGINEERING, 33 West 39th Street, New York City.

# Professional Engineering Directory

**For Consultants in Engineering and Allied Sciences**

**BLACK & VEATCH**
Consulting Engineers
Water, Steam and Electric Power Investigations, Design, Supervision of Construction, Valuation and Tests
4706 Broadway KANSAS CITY, MO.

**SANDERSON & PORTER**
ENGINEERS
FINANCING—REORGANIZATION—DESIGN—CONSTRUCTION
of
INDUSTRIALS and PUBLIC UTILITIES
Chicago New York San Francisco

**EDWARD E. CLEMENT**
Fellow AIEE
Attorney and Expert in Patent Causes
Soliciting, Consulation, Reports, Opinions
1509 Decatur St., N. W.
WASHINGTON, D. C.

**SARGENT & LUNDY**
Incorporated
ENGINEERS
140 South Dearborn Street
CHICAGO, ILLINOIS

**FRANK F. FOWLE & CO.**
Electrical and Mechanical Engineers
35 East Wacker Drive CHICAGO

**GEORGE T. SOUTHGATE**
ELECTRICAL AND THERMAL ENGINEER
Consultant in Design, Process and Patent Matters
114 East 32nd Street NEW YORK

**FREDERICK T. HICKS**
Registered Patent Attorney
Registered Professional Engineer
Ex-Member of Examining Staff of the United States Patent Office
1541 Nicholas Bldg. TOLEDO
Penobscot Bldg. DETROIT

**THE J. G. WHITE ENGINEERING CORPORATION**
Engineers—Constructors
Oil Refineries and Pipe Lines, Steam and Water Power Plants, Transmission Systems, Hotels, Apartments, Offices and Industrial Buildings, Railroads
80 BROAD STREET NEW YORK

**JACKSON & MORELAND**
ENGINEERS
Public Utilities—Industrials
Railroad Electrification
Designs and Supervision—Valuations
Economic and Operating Reports
BOSTON NEW YORK

**J. W. WOPAT**
Consulting Engineer
TELEPHONE ENGINEERING
Construction Supervision
Appraisals—Financial
Rate Investigations
303 East Berry St. Fort Wayne, Indiana

**Z. H. POLACHEK**
Reg. Patent Attorney
Professional Engineer
PATENT—TRADE MARK SPECIALIST
Individual or Yearly Basis
1234 Broadway (At 31 St) NEW YORK
Phone Longacre 5-3088

**J. G. WRAY & CO.**
Engineers
Utilities and Industrial Properties
Appraisals Construction Rate Surveys
Plans Organizations Estimates
Financial Investigations Management
105 West Adams St., Chicago

**WHEN YOU**
require technical advice—or
a solution to an engineering problem—
CONSULT THIS DIRECTORY

# Employment Bulletin

**Engineering Societies Employment Service**

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

**In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.**

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

## Men Available

E.E., 46, Am., 8 yrs exper distr, 2 yrs exper transm lines, 2 yrs exper substations, 7 yrs exper instal of elec eqpt. Desires engg or constr pos. E-33.

M.E. AND E.E., exper in the des and constr of metallurgical plants for copper and iron, and chem plants for sulphuric acid. Desires responsible pos with large oprtg co. E-31.

E.E., 27, single. Des, constr and oprn substations, swbds, wiring layouts. Exper in tel cables, splicing, testg, installing. Knowledge Spanish. Available immed. Location, anywhere. E-40.

TRANSF ENGR, Univ grad, married, exper in des and mfg of all types of transf. At present employed but desires pos with better opportunities. E-41.

E.E., R.P.I., 1932, Sigma Xi; 3 yrs' exper in precision parts mfr; desires a pos in the elec field, particularly des or pwr plant work. Location, U.S. E-42.

E.E., M.E., married, 25 yrs des, constr pwr houses, substations, distr systems indus plants, exec engg dept large util. Purchased engg eqpt foreign interest. English, German, Russian, Armenian, Turkish languages. E-37.

EXEC ENGR wants pos as supt or chief engr; util or large indus. Vast exper. Formerly chief engr in charge of des 400,000 kw plant. Writer and speaker. Now employed. E-38.

SMALL MOTORS—Mgmt trained E.E. with varied exper in devpmt and mfg for exec tech pos with financially sound firm. E-39.

E.E., 1935–1936 grad, for inspection work. Will specialize in pwr eqpt, motors, generators, voltage regulators, etc. E-29.

B.S., E.E., Cooper Union Inst of Tech, '35. Honor soc man. Exper aircraft instrument and eqpt field. Research and devpmt. Prefers NY or New England. E-36.

GRAD ENGR, B.E.E., '35; good scholastic rec; 18 mos in engg dept of elec motor mfg co; lab test work and special problems; interested in prod or commercial engg; location, Middlewest. E-44.

E.E. GRAD, 1932, single, 26. Sound motion picture, television, radio exper. Desires pos in sound engg field. Also grad DeForest's Training, Chicago. Location, N.E. or N.Y. Interested in projection or recording. E-45.

ELEC BACHELOR, Master MIT, Tau Beta Pi. Engg exper 2 yrs Gen Elec, 2 yrs Bell System. Also 3 yrs CCC Officer. Desires research, des with util or mfr. E-30.

INVENTOR, E.E.; exper on controls, resistance welding, oil burners, patent application prosecution, negotiations, contracts. Interested in diagnosis of troubles and their remedies. Location immaterial. E-43.

E.E., broad exper tech publicity, sales promotion, sales engg and sales mgmt; familiar mech as well as elec field. Now employed temporary project large pwr co. Available about July 1. E-34.

ASST PROF E.E., 38, B.S.E.E., M.S.E.E.; 4 yrs devpmt and practical exper; 13 yrs teaching D.C. and A.C. machy and elec des. At present on staff large recognized univ. Desires change. E-32.

B.S.E.E., 28, single; 4 yrs steam pwr plant engg, instruments, test, combustion; one yr testg tel eqpt. At present employed but desires better opportunity. E-35.

**ENGINEERING SOCIETIES EMPLOYMENT SERVICE**

NEW YORK 31 W. 39th St. | SAN FRANCISCO 57 Post St. | CHICAGO 211 W. Wacker Dr.

## Trade Literature

(*Cont'd from page 774*)

**New Instrument Slide Rule.**—An ingenious slide-rule indicator for use in selecting the proper instruments for any application, for central stations, industrial plants or transportation industry. Called the Instrulector, this slide-rule shows at a glance proper instruments to use, their range, approximate price, and size and descriptive literature available. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

**Cable Accessories.**—Catalog 371, 100 pp. Describes Anaconda insulated cable accessories–potheads of all types, together with instructions for installation; insulating compounds, etc. Dardelet threads are discussed and, for the first time, Everdur junction boxes are catalogued. The publication is notable for the ease with which the various types of accessories can be located, as well as the completeness of the descriptions. Anaconda Wire and Cable Co., 25 Broadway, New York.

**Circuit Breakers.**—Bulletin 3636, 4 pp. Describes type KL circuit breaker, a magnetically operated, latched-in switch, designed for severe service combined with fast switching action. The arcing contact design especially adapts this type of breaker for handling the inrush current of squirrel cage motors started at full voltage. Electrically operated, 1200 amperes and under, 600 volts a-c or less, 250 volts d-c or less. Manual operation can be provided. I-T-E Circuit Breaker Co., 19th and Hamilton Sts., Philadelphia, Pa.

**Vapor Lamp Transformer.**—Bulletin, 4 pp. Describes a new high intensity mercury vapor lamp transformer, the use of which, with proper lamps, provides far greater lighting efficiency than ordinarily available, according to the manufacturer. The transformer, adapted to mounting in any position, was developed especially for use with the new 400 watt high intensity mercury vapor lamp, combining the advantages of mercury vapor light in a practical lamp design that can be screwed into a socket of a conventional industrial reflector. The Acme Electric & Mfg. Co., 1446 Hamilton Ave., Cleveland, O.

**Laboratory Equipment.**—Descriptive Data 190, 40 pp., "Laboratory Apparatus for Educational Institutions." Describes the comprehensive line of equipment Westinghouse has developed for instruction and demonstration purposes. Many new pieces of apparatus are shown, including the multiple tap transformer, built-up transformer parts, variable capacitor, relay system boards, etc. Rotaprint 841, 28 pp., another publication of the same company, "Suggested Specifications for Electrical Laboratory Equipment." Covers electrical equipment from incoming lines to tools. Six different lists of apparatus are shown for large or small engineering schools and for similar classes of vocational schools. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

# Advertised Products Index

**AMMETER COMPENSATING COILS**
Minerallac Electric Co., Chicago

**AMMETERS, VOLTMETERS**
(See INSTRUMENTS, ELECTRICAL)

**BATTERY CHARGING APPARATUS**
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**BRUSHES, COMMUTATOR**
National Carbon Co., Inc., Cleveland, O.

**BUS BAR SUPPORTS**
General Electric Co., Schenectady, N. Y.

**CABLE ACCESSORIES**
Anaconda Wire & Cable Co., New York
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

**CAPACITORS**
Aervox Corp., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**CIRCUIT BREAKERS**

*Air-Enclosed*

General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

*Oil*

Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

**CLAMPS, GUY & CABLE**
Malleable Iron Fittings Co., Branford, Conn.

**CONDENSERS, ELECTROSTATIC**
Aerovox Corp., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh

**CONTACTS, TUNGSTEN, ETC.**
Fansteel Metallurgical Corp., N. Chicago, Ill.

**CONTROLLERS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Rowan Controller Co., Baltimore, Md.
Westinghouse E. & M. Co., E. Pittsburgh

**CONVERTERS, SYNCHRONOUS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**DYNAMOS**
(See GENERATORS AND MOTORS)

**ELECTRONIC TUBES**
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**GENERATORS AND MOTORS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Reliance Electric & Engg. Co., Cleveland
Westinghouse E. & M. Co., E. Pittsburgh

**GROUND RODS**
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.

**INSTRUMENTS, ELECTRICAL**

*Graphic*

Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

*Indicating*

Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

*Integrating*

Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

*Scientific, Laboratory, Testing*

Acme Elec. & Mfg. Co., Cleveland, O.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

**INSULATING MATERIALS**

*Cloth*

Minerallac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

*Compounds*

Minerallac Electric Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

**INSULATING MATERIALS** *(cont'd)*

*Moulded*

Bakelite Corp., New York
Westinghouse E. & M. Co., E. Pittsburgh

*Paper*

Insulation Manufacturers Corp., Chicago

*Tape, Friction*

Minerallac Electric Co., Chicago
Okonite Company, The Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

*Varnishes*

Bakelite Corp., New York
Minerallac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

**INSULATORS, PORCELAIN**
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Westinghouse E. & M. Co., E. Pittsburgh

**LIGHTNING ARRESTERS**
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**LOAD RECORDERS—CONTROLLERS**
Leeds & Northrup Co., Philadelphia

**LOCOMOTIVES, ELECTRIC**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**METERS, ELECTRICAL**
(See INSTRUMENTS, ELECTRICAL)

**MOTORS**
(See GENERATORS AND MOTORS)

**POLE LINE HARDWARE**
Malleable Iron Fittings Co., Branford, Conn.
Ohio Brass Co., Mansfield, O.

**POLE MOUNTS**
Malleable Iron Fittings Co., Branford, Conn.

**RECTIFIERS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**REGULATORS, VOLTAGE**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

**RELAYS**
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

**RESISTORS**
Aerovox Corp., Brooklyn, N. Y.
General Radio Co., Cambridge, Mass.
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh.

**RHEOSTATS, LABORATORY**
General Electric Co., Schenectady, N. Y.
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

**SHEETS, ELECTRICAL**
Carnegie-Illinois Steel Corp., Pittsburgh

**SUB-STATIONS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.

**SURGE ABSORBERS**
Ferranti Electric, Inc., New York

**SWITCHBOARDS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

**SWITCHES, AUTOMATIC TIME**
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

**SWITCHES, DISCONNECT**
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

**SWITCHES, GENERATOR FIELD**
I-T-E Circuit Breaker Co., Philadelphia

**TOWERS, TRANSMISSION**
American Bridge Co., Pittsburgh

**TRANSFORMERS**
Acme Elec. & Mfg. Co., Cleveland, O.
Allis-Chalmers Mfg. Co., Milwaukee
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh

**TURBINE GENERATORS**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**TURBINES**
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**WATCHES, STOP**
Meylan, A. R. & J. E., New York

**WELDERS, ARC**
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

**WELDING WIRE**
American Steel & Wire Co., Chicago
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

**WIRES AND CABLES**

*Aluminum*

Aluminum Co. of America, Pittsburgh

*Armored Cable*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins.Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Asbestos Covered*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Bare Copper*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
Roebling's Sons Co., John A., Trenton, N. J.
General Cable Corp., New York

*Bronze*

Copperweld Steel Co., Glassport, Pa.

*Copper Covered Steel*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York

*Flexible Cord*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins.Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Heavy Duty Cord*

American Steel & Wire Co. Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins.Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Okonite Company, The Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Lead Covered (Paper and Var. Cambric Ins.)*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire &Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Magnet*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire &Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

*Rubber Insulated*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire &Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y
Kerite Ins. Wire & Cable Co., New Yor
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Tree Wire*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire &Cable Co., Trenton, N.J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

*Weatherproof*

American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire &Cable Co., Trenton, N.J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.


EXCHANGE 2368
SYMBOL OF SERVICE
This country's good telephone service did not just happen. It has been made possible by the organization and development of the Bell System.
BELL TELEPHONE SYSTEM
AMERICAN TELEPHONE & TELEGRAPH CO.
BELL SYSTEM
AND ASSOCIATED COMPANIES

# ADVERTISERS